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GUIDELINES FOR AIR QUALITY MAINTENANCE PLANNING AND ANALYSIS. VOLUME 10. REVIEWING NEW STATIONARY SOURCES

ENVIRONMENTAL PROTECTION AGENCY

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Methods for assessing the impact of proposed point sources of pollution on maximum short term ambient concentrations and on annual mean ambient concentrations are presented. The importance of control devices, stack characteristics, meteorological and topographical influences in determining a source's impact on ambient air quality is also discussed. Information contained in these guidelines may be used to assist air pollution control agencies in determining whether a proposed point source would be consistent with the need to maintain air quality within prescribed air quality levels.

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GUIDELINES FOR AIR QUALITY MAINTENANCE PLANNING AND ANALYSIS VOLUME 10 : REVIEWING NEW STATIONARY SOURCES

ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711
September 1974

OAQPS GUIDELINE SERIES

The guideline series of reports is being issued by the Office of Air Quality Planning and Standards (OAQPS) to provide information to state and local air pollution control agencies; for example, to provide guidance on the acquisition and processing of air quality data and on the planning and analysis requisite for the maintenance of air quality. Reports published in this series will be available - as supplies permit - from the Air Pollution Technical Information Center, Research Triangle Park, North Carolina 27711; or, for a nominal fee, from the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22151.

This report was furnished to the Environmental Protection Agency by Geomet, Inc., Rockville, Maryland, in fulfillment of Task Order No. 2, Contract No. 68-02-1094. Prior to final preparation, the report underwent extensive review and editing by the Environmental Protection Agency and other concerned organizations. The contents reflect current Agency thinking and are subject to clarification, procedural change, and other minor modification prior to condensation for inclusion in Requirements for Preparation, Adoption, and Submittal of Implementation Plans (40 CFR Part 51).

Publication No. EPA-450/4-74-011
(OAQPS Guideline No. 1.2-029)

FOREWORD

This document is the tenth in a series comprising Guidelines for Air Quality Maintenance Planning and Analysis. The intent of the series is to provide State and local agencies with information and guidance for the preparation of Air Quality Maintenance Plans required under 40 CFR 51. The volumes in this series are:

Volume 1:	Designation of Air Quality Maintenance Areas
Volume 2:	Plan Preparation
Volume 3:	Control Strategies
Volume 4:	Land Use and Transportation Considcration
Volume 5:	Case Studies in Plan Development
Volume 6:	Overview of Air Quality Maintenance Area Analysis
Volume 7:	Projecting County Emissions
Volume 8:	Computer-Assisted Area Source Emissions Gridding Procedure
Volume 9:	Evaluating Indirect Sources
Volume 10:	Reviewing New Stationary Sources
Volume 11:	Air Quality Monitoring and Data Analysis
Volume 12:	Applying Atmospheric Simulation Models to Air Quality Maintenance Areas

Additional volumes may be issued.

All references to 40 CFR Part 51 in this document are to the regulations as amended through July 1974.

NOTE

This guideline is being released in its present form in order to allow its immediate use by State and local agencies. This guideline may be reissued in the near future in order to incorporate comments and suggested improvements offered by the EPA Regional Offices and by State and local agencies and other concerned groups.

PREFACE

Volumes 7, 8 and 13 present procedures which can be used to project and allocate emissions within a county. Volume 12 discusses how projected emission inventories incorporating various levels of detail may be used in atmospheric simulation models (which have been calibrated with valid air quality data) to project air quality levels within a county. It is apparent from Volumes 7, 8 and 13 that it may frequently be extremely difficult to project emissions from new point sources of pollution. The difficulties are threefold:

(1) Uncertainty about the process and control devices to be used, resulting in uncertainty about the quantity and type of emissions.

(2) Uncertainty about the location of the new source.

(3) Uncertainty about the stack design parameters of the new source.

Lack of precise knowledge about any of the above three variables greatly decreases the reliability with which the analyst can (a) estimate the adequacy of emission density limitations for maintaining ambient air quality standards, and (b) estimate whether an individual point source is likely to result in localized violations of ambient air quality standards.

The foregoing discussion strongly suggests that an air quality maintenance plan require the analysis of proposed new point sources to be a two-tiered procedure. The first step would require an analysis

in which county emissions are projected and allocated using procedures similar to those outlined in Volumes 7, 8 and 13. This information would then be used in one or more calibrated atmospheric simulation models, similar to those outlined in Volume 12, to estimate whether ambient air quality standards would be met under the projected scenario. Use of the atmospheric simulation models can be extended to prescribe emission limitations for the industrial, residential and commercial zones designated within the county. The projected distribution of air quality levels obtained by using projected distributions of emissions as input to calibrated atmospheric simulation models would serve to estimate urban background concentrations.

The second step in the analysis of a proposed point source should be implemented after a concrete proposal, specifying the source's location, stack design parameters and net emissions after the application of control devices, has been received. The emissions estimated for the source would be allocated to it from the remaining available allowable emissions estimated in the first step of the analysis. Assuming there are sufficient available emissions to perform this allocation, the second step should proceed. The purpose of the second step is to insure that the design, location and emission control devices to be used by the proposed source are sufficient to avoid the threat of localized violations of ambient air quality standards. This assurance could be gained by performing an analysis of the source's impact and superimposing it on the projected urban background concentration at appropriate locations. The purpose of Volume 10 is to suggest methods which may

be used in estimating the impact of an individual point source of pollution on ambient air quality. These methods may be used to provide assurance that a new source will not violate standards and provide insight into strategies which might be effective in reducing the impact of an individual source on air quality.

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CHAPTER 1

INTRODUCTION

BACKGROUND

In response to the requirements imposed by 40 CFR part 51 (which establishes requirements for preparation, adoption, and submittal of state implementation plans for attaining and maintaining national standards of air quality), each state must adopt a procedure for the review of new sources and modifications of sources of air pollution. The adopted procedure will enable a state or local agency to determine whether the new source or modification will interfere with the attainment or maintenance of national standards. The review will consider emissions directly from the source and indirectly from mobile source activities associated with the stationary source. Thus, the review will extend to facilities such as airports, amusement parks, highways, and shopping centers. This document is concerned primarily with the review of stationary sources. For help in reviewing sources with significant mobile source activity, consult "Guidelines for Review of Complex Sources" (in preparation, 1974). This document discusses analytical methods which will be helpful in formulating review procedures and discusses information requirements for using the methods. The intent of this document is to provide sufficient guidelines to state and local control agencies that the need for major revisions to state implementation plans based on these guidelines will be greatly decreased.

PURPOSE OF THE REVIEW

The review procedures to be adopted by state and local air pollution control agencies have three purposes:

- To provide assurance that a new source will not cause ambient air quality standards to be violated.
- To bring to light procedures, source designs and siting alternatives which would further reduce the impact of air pollutants, especially on the more susceptible individuals and crops.
- To provide sufficient knowledge of potential air pollution problems resulting from the new source's existence or subsequent growth that such problems can be adequately dealt with.

HOW TO USE THIS DOCUMENT

The techniques presented in this document are useful in estimating air quality levels which result from emissions by a single new or modified source. It is presumed that the present and future air quality in areas affected by the new or modified source is known or can be estimated from other information. This includes consideration of the extent to which air quality levels from present sources will be reduced in the future by the application of control strategies. Such strategies are designed to meet national air quality standards and to allow for future development. By adding the air pollutant concentrations calculated for the new source to both the present and the projected future concentrations, one can determine whether the new source will likely result in concentrations which exceed national standards. The result will also provide guidance as to whether the new source conforms to applicable control strategies in view of additional sources which may be expected within the projected degree of future growth and development.

Selection of Techniques

The methods and techniques presented herein are suggestions and not rigid requirements. There are many situations in which the techniques may be applied with a reasonably high degree of confidence. Their validity is based on results averaged over a large number of individual receptor locations. However, even under the most favorable conditions, e.g., situations with well defined air flow in terrain without irregular topographical features such as valleys, ridges, and large lakes, air quality estimates in terms of ground level concentration at a single receptor location may vary from

observed values by a factor of three. When irregular topographical features are present, the results are less certain, and the services of an experienced air pollution meteorologist should be sought in estimating air quality levels. The methods presented in this document provide some limited guidance for estimating the effects of irregular topographical features.

Whether an emitted pollutant is photochemically reactive or not will affect the technique selected. However, while references are given to methods for treating photochemical reactions, suitable techniques are not included in this document.

Another consideration which affects the selection of a technique is the averaging period which must be considered. The national air quality standards are defined for different periods for each pollutant. These are listed in Table 1-1.

Table 1-1. PHOTOCHEMICAL REACTIVITY AND PERIODS FOR WHICH NATIONAL AIR QUALITY STANDARDS EXIST FOR SIX POLLUTANTS

Pollutant	Photochemical Reactivity	Periods with National Standards					
		Annual	Max(a) 24-hr	Max(a) 8-hr	Max(a) 3-hr	Max(a) 6-9 am	Max(a) 1-hr
Sulfur Dioxide	Stable	X	X		X		
Particulate	Stable	X	X				
Carbon Monoxide	Stable			X			X
Nitrogen Dioxide	Reactive	X					
Hydrocarbons	Reactive					X	
Photochemical Oxidants	Reactive						X

(a) Max. refers to a maximum concentration not to be exceeded more often than once a year.

Degree of Detail

For sources located in flat terrain, in which the emissions affect relatively clean areas, and with continuous emission rates, a few simple calculations are adequate. When nearby lakes or mountains, highly variable emission rates, possible downwash problems or other localized effects are present, detailed study is required.

Data Requirements

The data required to carry out the techniques presented here include emission data, meteorological data, and topographical maps. The emission data is described in Chapter 2. The meteorological data is described in Chapter 3. Topographical maps may be obtained from the U.S. Geological Survey.

CHAPTER 2

EMISSION DATA

EMISSIONS AND EFFECTIVENESS OF CONTROLS OF POINT SOURCES

An important part of the review process must include a determination of how much of what pollutants are emitted where and when. If the pollutants are not emitted at a constant rate (most are not), information should be obtained on how the emissions may vary with season, day of the week, and hour of the day. In most cases the emissions will vary with the source's production rate, which can be specified in terms of output units, e.g., for each kilowatt-hour of electricity produced by a fossil-fuel power plant, a known amount of fuel will be consumed and a known amount of each pollutant will be emitted. The source operator should be able to determine appropriate emission factors, giving the amount of each pollutant emitted per unit of the source's related production process.

Four possible bases for determining emission factors, in decreasing order of confidence are:

- Stack-test results or other emission measurements from an identical or equivalent source
- Material balance calculations based on engineering knowledge of the process
- Emission factors derived for similar sources or taken from a compilation by the U.S. Environmental Protection Agency (1973a)
- Engineering judgment.

For pollutants which are emitted in direct proportion to production process rates, variations in emission rates can be determined from variation in production rates. The source operator should be requested to define his planned hours of operation for each day of the week. If his production rate varies with hour of the day, day of the week, or month of the year, the expected production rate should be defined for all periods as a percentage of the maximum production rate. With this information, the maximum production rate and the emission factor for each pollutant, the emissions can be determined for any hour, three-hour, eight-hour, or 24-hour period.

Some emissions are best related to factors other than production rates. Examples of emissions not directly related to production rates are emissions from fuel burned for space heat, evaporation of stored volatile materials, and fugitive dust from stored powders or from dirt roads. The following equation relates emissions from space heating fuel consumption to average temperature, for temperatures below 18.3°C (65°F):

$$Q = \frac{EF}{24}(18.3 - T) \qquad (T < 18.3°C) \qquad (2\text{-}1)$$

where Q = emission rate, kg/hr
E = emission factor, kg/(unit fuel)
T = average temperature, °C
F = space heat fuel factor, (unit fuel)/(deg. day)

Space heat fuel requirements are usually known in terms of degree days.* Most fuel distributors estimate space heat fuel factors for each customer and keep track of the seasonal accumulation of degree days in order to schedule fuel deliveries. For more detailed treatment of emissions related to space heating refer to analyses by Turner (1968), Roberts (1970), and Koch and Thayer (1971).

---

* 65°F (18.3°C) less the average of the daily maximum and minimum temperatures is the number of daily degree days.

For stored volatile materials EPA has developed convenient methods of estimating evaporation emissions from the storage and transportation of petroleum products, dry cleaning, and surface coating operations (U.S. Environmental Protection Agency 1973a including Supplement No. 1).

For fugitive sources methods of estimating emissions are necessarily subjective. However, emission factors have been developed for some sources, e.g., gravel stored in outside piles (U.S. EPA 1973a). Also, guidelines are available for estimating amounts of material burned per acre by forest fires, slash burning, and agricultural burning (U.S. EPA 1973b). These estimates combined with available emission factors for fires (U.S. EPA 1973a) may be used to determine annual and short-term emission rates. Unfortunately, little or no information is available to estimate emissions from traffic over dirt roads and other types of fugitive sources of emissions.

Where emissions are reduced by control equipment, the effectiveness of such controls must be included in the emission estimates. The source operator will be able to estimate what the effectiveness is and what conditions alter its effectiveness and to what degree. A survey of the types of controls and the control efficiencies which have been reported in the National Emissions Data System (NEDS) for various types of sources is available from EPA (Vatavuk 1973). A number of other references are also available which provide more detailed guidelines about emission controls (e.g., Danielson 1973, Lund 1971, Stern 1968, U.S. Dept. of HEW 1969a,b and 1970a,b,c; U.S. EPA 1971 and 1973c).

STACK CHARACTERISTICS

The height, buoyancy, momentum and relation to surrounding topography are all important characteristics of emitted pollutants. As a general rule

the point of emission is a stack. The following characteristics of the stack and its effluents should be provided by the source operator:

- Height
- Exit diameter (may be approximated by 1.13 times the square root of the cross-sectional area for non-circular flues)
- Exit velocity
- Exit temperature (buoyant plumes only).

With the above information, the plume rise can be calculated for the stack effluents. The recommended method for estimating plume rise is given in Chapter 4.

If there is no stack so that the emissions are released from vents on the top or side of a building, the emissions will be subjected to mixing in the turbulent cavity immediately downwind of the building. In this case the dimensions of the building, including height, length, and width, and its orientation should be specified. These will be used to determine the minimum crosswind area of the building. In addition, an estimate is required as to how much the cross-sectional area of the downwind cavity is altered by the building shape. Typical shape factors vary from 0.5 for a highly streamlined building to 2.0 for the conventional bluff shape.

If the temperature and velocity of the stack gas effluent are not available from the source operator, some guideline estimates are available (Engineering-Science, Inc. 1971).

LOCATION AND TOPOGRAPHY

The location of the source should be determined as accurately as possible (e.g., within $\pm$ 0.1 km) in terms of convenient coordinates. Universal Transverse Mercator Coordinates are recommended since these are the coordinates most commonly used in air pollution reporting systems.

Any significant topographical feature in the vicinity of the source should be noted. U.S. Geological Survey Maps are convenient for this purpose.

Important features to note are large lakes or seashore, nearby hills and mountains, valley configurations, and general terrain roughness. These characteristics influence diffusion modeling considerations.

MERGED PARAMETERS FOR MULTIPLE STACKS

Sources which emit the same pollutant from several stacks in close proximity may be analyzed by treating the emissions as coming from a single representative stack. The following rule which is recommended for combining emissions from similar boilers for NEDS may be used to select stack characteristics to represent the combined emissions (U.S. EPA 1973b). For each stack compute parameter K as follows:

$$K = \frac{h\ V\ T_s}{Q} \qquad (2\text{-}2)$$

where h = stack height

$V = \frac{\pi}{4} d^2 v_s$ = stack gas volume flow rate

d = stack exit diameter

v_s = stack gas exit velocity

T_s = stack gas exit temperature

Q = stack emission rate.

Use the height, diameter, exit velocity and exit temperature of the stack with the lowest value of K. Use the sum of emissions for all stacks as the emission rate.

If the stacks are widely dispersed, use of a single representative stack for the combined emissions will greatly overestimate the concentrations from the plant. In the case of a very large complex industrial plant, several representative combined stacks may be used.

CHAPTER 3

METEOROLOGICAL DATA

The methods of estimation presented in Chapter 4 require the use of the following meteorological parameters:

- Temperature
- Incoming solar radiation
- Cloud cover and ceiling height
- Wind direction and speed
- Mixing layer height

In some Air Quality Control Regions (AQCR) these parameters are routinely measured and recorded in a data bank along with air quality measurements. More generally, however, these parameters must be obtained from the National Climatic Center in Asheville, North Carolina. Limited data may also be obtained directly from local National Oceanic and Atmospheric Administration (NOAA) observing stations.

A discussion of common measurements of each of the above parameters and of their relation to the values required for the methods of Chapter 4 follows.

Temperature

Estimates of temperature are required to estimate the emission rate of pollutants associated with the combustion of fuel for space heat and to estimate the plume rise of buoyant exhaust gases. In addition to standard hourly and three-hourly records of temperature, a number of useful climatological summaries are available (see Table 3-1). In some cases it will be necessary to convert reported temperatures to other units. The following relationships may be useful:

$$C = (F-32)(5/9)$$

$$K = C + 273$$

Table 3-1. SOURCES OF TEMPERATURE DATA

Temperature Characteristic	Sources*
Hourly Observation	NCC
Three-Hourly Observation	NCC
Monthly and Annual	
Daily Max.	LCD, ACB, WWAS
Daily Min.	LCD, ACB, WWAS
Mean	LCD, SMOS-E
Std. Deviation	SMOS-E
Degree Days	LCD
Extreme Max.	LCD, ACB, WWAS
Extreme Min.	LCD, ACB, WWAS
Monthly and Annual Freq. Dist.	
Daily Max.	AFSUM-A
Daily Min.	SMOS-E, AFSUM-A
Daily Mean	SMOS-E, AFSUM-A
Three-Hourly	SSMO-13, 17; SMOS-E; AFSUM-A

*NCC - National Climatic Center, Federal Building, Asheville, N. C. 28801

LCD -"Local Climatological Data", NCC

ACB -"AWS Climatic Brief", NCC

WWAS - "World-Wide Airfield Summaries", NCC

SMOS-E - "Summary of Meteorological Observations, Surface, Part E", NCC

AFSUM-A - "Summary of Surface Weather Observations - A Summary", NCC

SSMO-13, 17 - "Summary of Synoptic Meteorological Observations", Tables 13 and 17, NCC

where C = temperature, °C
F = temperature, °F
K = absolute temperature, °K

Incoming Solar Radiation

The intensity of incoming solar radiation is required to estimate atmospheric stability. Although it is not routinely measured at most locations, it may be estimated from the solar elevation angle and the amount of cloud cover.

For the purpose of estimating stability, incoming radiation may be qualitatively classified as strong, moderate or slight. "Strong" incoming solar radiation corresponds to a solar altitude greater than 60° with clear skies; "moderate" insolation corresponds to a solar altitude between 35° and 60° with clear skies; "slight" insolation corresponds to a solar altitude from 15° to 35° with clear skies. Table 170, Solar Altitude and Azimuth, in the Smithsonian Meteorological Tables (List, 1951) can be used in determining the solar altitude. Cloudiness will decrease incoming solar radiation and should be considered along with solar altitude in determining solar radiation. Incoming radiation that would be strong with clear skies can be expected to be reduced to moderate with broken (5/8 to 7/8 cloud cover) middle clouds and to slight with broken low clouds. An objective system of classifying stability from hourly meteorological observations based on the above method has been suggested (Turner, 1961).

Turner's objective method is presented in Tables 3-2 and 3-3. Total cloud amount and cloud ceiling height are discussed in the following section. The solar altitude angle may be obtained from List (1951) or from the following equation.

Table 3-2. RADIATION INDEX VALUES

Time of Day*	Total Cloud Amount (N)	Ceiling Height (c), (ft)	Net Radiation Index for Indicated Solar Altitude (a)			
			$a \leq 15°$	$15° < a \leq 35°$	$35° < a \leq 60°$	$a > 60°$
Night	$N \leq 0.4$	-	-2	-	-	-
Night	$0.4 < N < 1.0$	-	-1	-	-	-
Night	$N = 1.0$	$c < 7{,}000$	0	-	-	-
Night	$N = 1.0$	$c \geq 7{,}000$	-1	-	-	-
Day**	$N < 1.0$	$c \geq 16{,}000$	1	2	3	4
Day	$0.5 < N < 1.0$	$c < 7{,}000$	1	1	1	2
Day	$0.5 > N < 1.0$	$16{,}000 > c \leq 7{,}000$	1	1	2	3
Day	$N = 1.0$	$c \leq 7{,}000$	0	0	0	0
Day	$N = 1.0$	$16{,}000 > c \geq 7{,}000$	1	1	1	2
Day	$N = 1.0$	$c \geq 16{,}000$	1	1	2	3

*Night refers to time from 1 hour before sunset to 1 hour past sunrise.

**This line includes conditions of clear or scattered clouds with no cloud ceiling.

Table 3-3. METEOROLOGICAL STABILITY CLASSIFICATIONS FOR CHARACTERIZING DIFFUSION

Wind Speed (Knots)	Stability Class for Indicated Net Radiation Index*						
	4	3	2	1	0	-1	-2
0, 1	A	A	B	C	D	E	E
2, 3	A	B	B	C	D	E	E
4, 5	A	B	C	D	D	E	E
6	B	B	C	D	D	E	E
7	B	B	C	D	D	D	E
8, 9	B	C	C	D	D	D	E
10	C	C	D	D	D	D	E
11	C	C	D	D	D	D	D
≥ 12	C	D	D	D	D	D	D

*Net Radiation Index Values are Given in Table 3-2.

$$\alpha = \arcsin\left\{\sin\phi \sin\delta + \cos\phi \cos\delta \cos\left[\frac{\pi}{12}(h - 12)\right]\right\}$$

$$\delta = 23.5\left(\frac{\pi}{180}\right) \sin\left\{\frac{\pi}{180}\left[30(m-1) + d-80\right]\right\}$$

where

α = solar altitude
δ = solar declination
m = month of year
d = day of month
h = hour of day (local standard time)
ϕ = latitude.

Another method of estimating the intensity of incoming solar radiation suggested by Ludwig, et al (1970) is the following:

Slight $\equiv I \leq 0.33$
Moderate $\equiv 0.33 < I \leq 0.67$
Strong $\equiv 0.67 < I$

where $I = (1-0.5N) \sin \alpha$
N = cloud cover (fraction of sky obscured)
α = solar altitude angle

Cloud Cover and Ceiling Height

Hourly or three-hourly observations of surface weather observations, which may be ordered from NCC, include total cloud amount and cloud ceiling height. These observations are used to determine atmospheric stability classes as indicated in a preceding section.

Wind Speed and Direction

Wind speed and direction are available as part of hourly or three-hourly weather records from NCC. Surface wind direction and speed are also commonly measured as a part of AQCR monitoring systems.

Climatological values of wind speed and direction may also be useful. For example, in addition to the joint frequency distribution of wind speed, wind direction and stability, distributions of wind speed or direction are avaialble as a function of hour of the day on both an annual and a monthly basis.

Since January 1964, wind directions have been generally reported to the nearest 10 degrees azimuth. However, climatological summaries of wind directions may be in terms of 8 or 16 compass points instead of 10 degrees azimuth.

Wind speeds are usually measured at a height near 6 meters (20 feet). It is desirable to get an average wind speed over the layer affected by the plume. The following equation may be used to estimate an average layer wind speed.

$$\bar{u} = \frac{u_1}{p+1} \left(\frac{L}{z_1} \right)^p$$

where $\bar{u}$ = average wind speed for the plume

z_1 = anemometer height

u_1 = observed wind speed

L = height to top of plume (use height of the mixing layer or the effective source height plus $2\sigma_z$, whichever is less)

p = wind profile parameter (see Table 3-4).

Table 3-4. WIND PROFILE PARAMETERS AS A FUNCTION OF ATMOSPHERIC STABILITY

Stability Category	Exponent of Wind Speed Profile
A	0.1
B	0.15
C	0.2
D	0.25
E	0.3
F	0.35, 0.5*

Joint Frequency Distribution of Wind Direction, Wind Speed and Stability

Climatological joint frequencies of occurrence of wind direction, wind speed and stability by annual, seasonal or monthly periods may be requested directly from the National Climatic Center (NCC), Asheville, N.C. 28801.

Mixing Layer Height

Climatological summaries of mixing layer heights are available from EPA (Holzworth 1972). Two relevant summaries are presented in Figures 4-7 and 4-8. In addition, the mixing layer height may be estimated from radiosonde observations available from NCC. If radiosonde observations are not available from a nearby station, spatial interpolation may be necessary between two or more stations. During daytime hours, the mixing layer height may be estimated by projecting the ground level temperature adiabatically (along a line of constant potential temperature) on a thermodynamic chart until it intersects the temperature height graph from the most recent radiosonde observation. The height of the intersection will be the height of the mixing layer. During nocturnal hours, a stable layer will likely form over rural terrain, in which case there is no mixing

*A value of 0.35 is appropriate for stacks in excess of 100m. A value of 0.5 may be used when the plume height does not exceed 100m. These values are designed to represent the very sharp shear in wind speeds which exists in a shallow surface layer during very stable conditions.

layer. Over urban terrain, a new mixing layer will form beneath the late afternoon mixing layer. The height of the urban mixing layer can be determined directly from a radiosonde sounding if one is available for the urban area. If, as is more commonly the case, only a rural sounding is available, the urban morning mixing layer height can be estimated by adding 5°C to the minimum morning temperature and projecting this ground level temperature adiabatically until it intersects the temperature sounding as is done for afternoon mixing heights. It is recommended that the late afternoon mixing layer height be continued until midnight and that the mixing height determined for the morning sounding of the next day be used after midnight.

CHAPTER 4

METHODS OF ANALYSIS

Methods of estimating concentrations of pollutants emitted by a new (or modified) source are presented for the following types of considerations:

- Maximum short-term concentration
- Annual mean concentrations
- Short-term concentrations at critical locations.

In order to perform the analyses and calculations suggested here, it is necessary to obtain meteorological data for the area affected by the new source. It may also be necessary to supplement or verify the validity of the emission and stack data supplied by the new source owners and operators. Chapter 2 discusses sources of emission, emission control and stack information. The types of meteorological data needed and suggested sources for this data are discussed in Chapter 3.

MAXIMUM SHORT-TERM CONCENTRATIONS

One-hour ground-level concentrations from emissions by a single source can best be estimated by means of the Gaussian plume equation. For a discussion of this equation, including its various uses and limitations the reader should consult the Workbook of Atmospheric Dispersion Estimates (Turner 1970). The one-hour concentrations may be used to estimate concentrations for longer averaging periods using empirical conversion factors which are presented in the methodologies which follow. A method is presented for estimating maximum short-term concentrations from sources with each of the following types of emission situations:

- Stack with significant plume rise (jet or buoyant plume)
- Stack with little or no plume rise

- Ground-level source with little or no plume rise
- Emissions from a rooftop or side of a building with little or no plume rise
- Fumigation from an elevated source.

Most sources will fit the first category, i.e., they are well defined stacks with or without plume rise. If the emissions from these sources occur at a place where and during a time when fumigation effects are present, this effect should be evaluated separately. Sources (e.g., dumps or open burning areas) whose emissions undergo significant plume rise, but which are not emitted from a well defined stack, may be treated by the elevated source methodology by using the average plume rise as the source height. Fugitive emissions from sources without well defined emission points may be treated either as ground level sources or as emissions from a building.

The following guide outlines the methods recommended for estimating maximum short-term concentrations:

1. Determine critical wind speed (Equation 4-1) for emissions released 10 m or more above ground level. If the critical wind speed equals or exceeds 1 m/sec, use the methodology for stacks with significant plume rise - see page 26.
2. If the critical wind speed is less than 1 m/sec and the release height is 10 m or more (including sources such as outside burning with an estimated effective plume height in excess of 10 m), use the methodology for stacks with little or no plume rise - see page 30.
3. Treat all other sources by using the ground source methodology - see page 32.
4. If the emissions are released from a building (through a short stack or vent) such that the release point is less than or equal to 1.5 times the building height, use the

building methodology in addition to one of the three above - see page 31.

5. If the first method is selected, evaluate fumigation effects - see page 32.

Critical Wind Speed

For a given set of stack characteristics, the Gaussian plume equation can be used to determine the meteorological conditions which will be associated with the maximum ground-level concentrations and where the maximum will occur. The ratio of maximum ground level concentration times wind speed to source emission rate $(\chi u/Q)_{max}$ is given as a function of downwind distance (x_{max}) for various categories of atmospheric stability in Figures 4-1 and 4-2. The values in Figure 4-1 are for a smooth, level (rural) terrain; Figure 4-2, for level, urban terrain. The categories of atmospheric stability used on the graphs are associated with the meteorological conditions listed in Table 4-1. An alternate method of determining these stability categories is given in Table 3-2 and 3-3. Each point on the graphs corresponds to a unique effective source height, i.e., physical stack height plus the plume rise due to the buoyancy and momentum of the exiting stack gases. Under neutral and unstable atmospheric conditions (stability classes A through D) there are a critical wind speed u_{crit} and a critical plume height H_{crit} which result in the maximum ground level concentration.

$$u_{crit} = \frac{K}{h}\frac{p}{q} \qquad (4\text{-}1)$$

$$H_{crit} = \left(\frac{q}{p} + 1\right)h \qquad (4\text{-}2)$$

where h = stack height

K = plume rise parameter (see Table 4-3).

Determine the smallest critical wind speed over all four stability classes and all distance ranges.

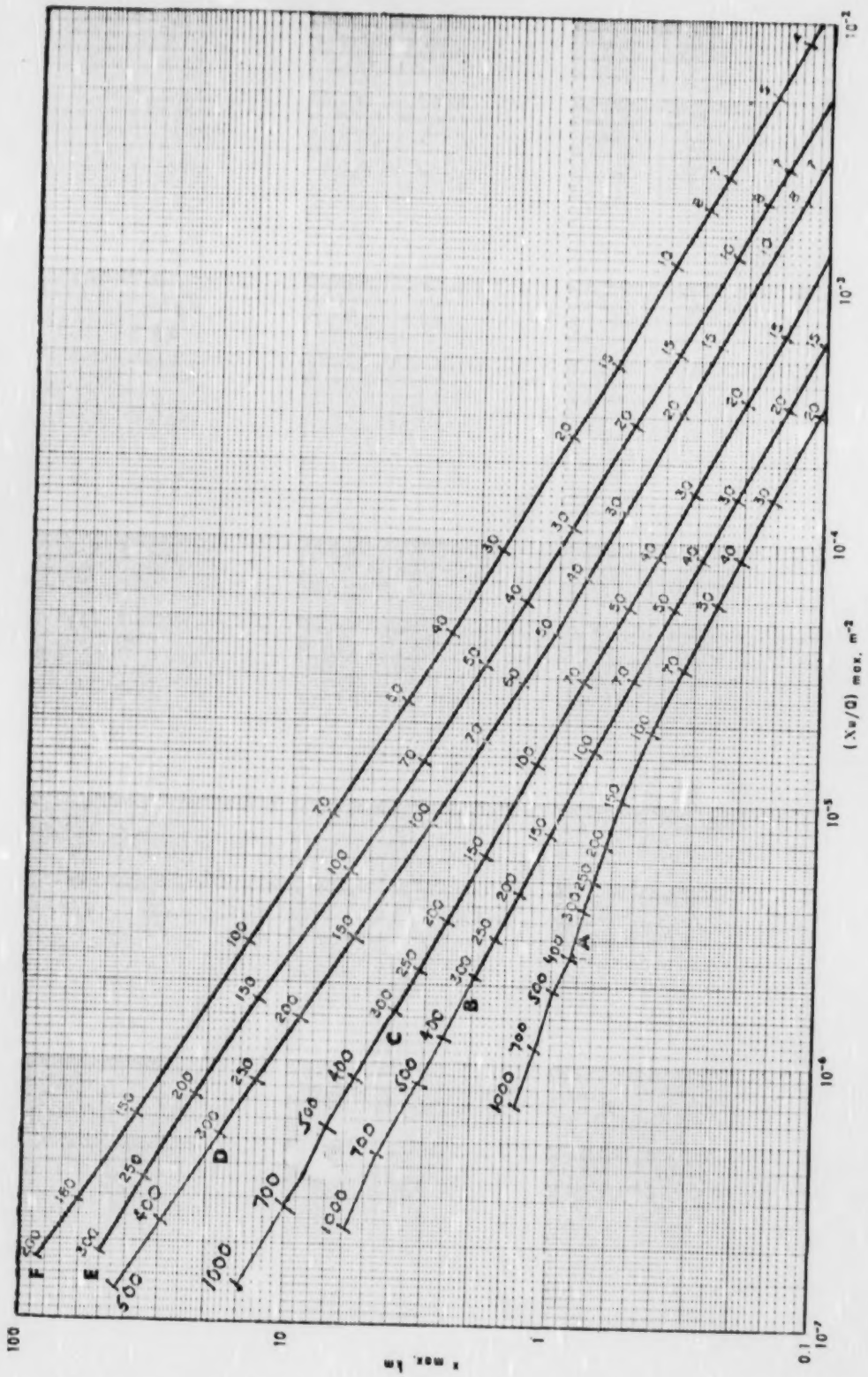

Figure 4-1. Distance of Maximum Concentration and Maximum xu/Q as a Function of Stability Class and Effective Height (Meters) of Emission Over Rural Terrain (Turner 1970)

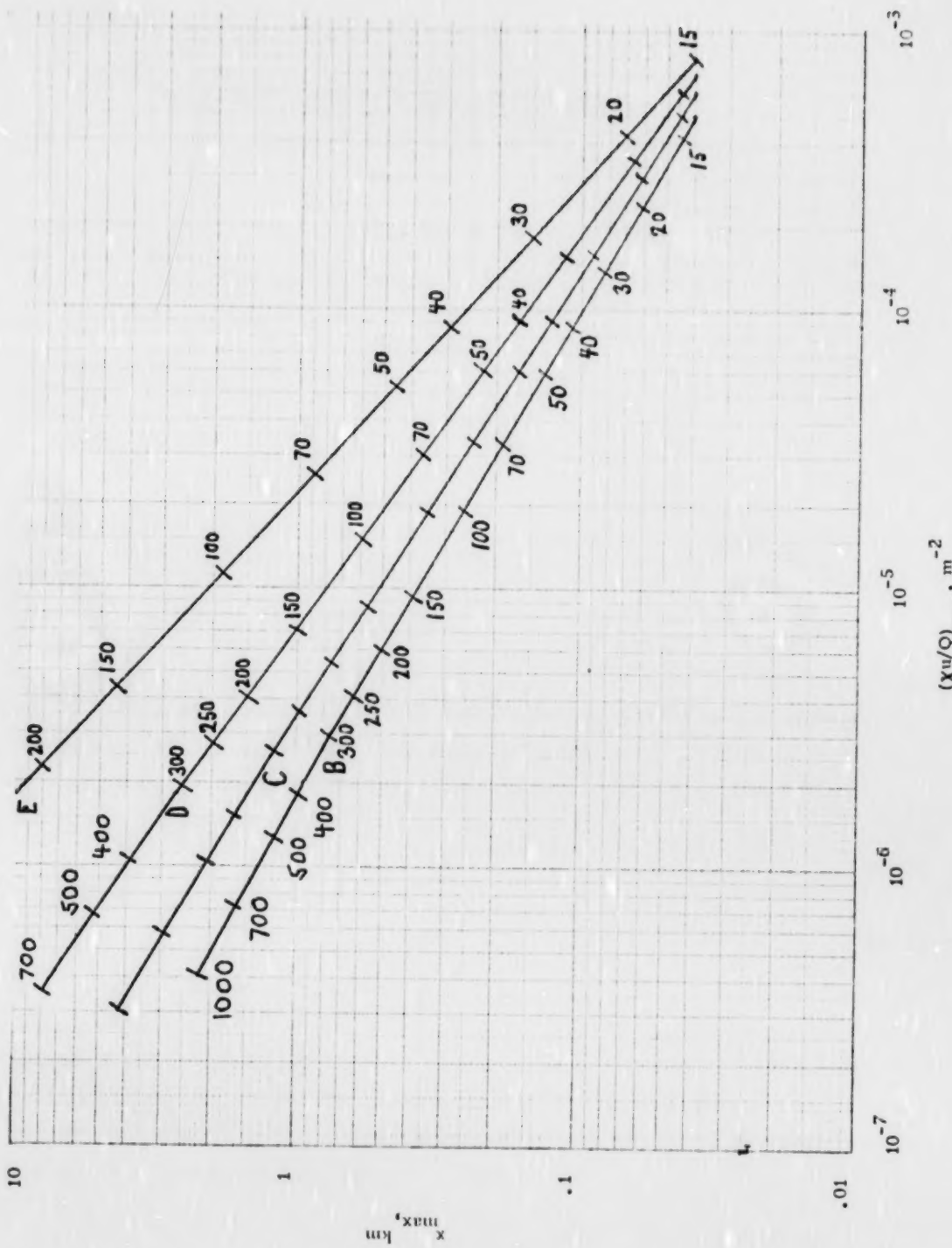

Figure 4-2. Distance of Maximum Concentration and Maximum xu/Q as a Function of Stability Class and Effective Height (Meters) of Emission Over Urban Terrain

Table 4-1. KEY TO STABILITY CATEGORIES

Surface Wind Speed (at 10 m), m sec^{-1}	Day			Night	
	Incoming Solar Radiation			Thinly Overcast or ≥4/8 Low Cloud	≤ 3/8 Cloud
	Strong	Moderate	Slight		
< 2	A	A-B	B		
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
> 6	C	D	D	D	D

The netural class, D, should be assumed for overcast conditions during day or night. Where two classes are indicated for the same conditions (e.g., A-B), an interpolation between the two classes is appropriate.

The variables p and q are related to the diffusion parameters σ_y and σ_z, respectively, in the Gaussian plume equation when they are expressed as power functions of downwind distance (x) from the source in the form:

$$\sigma_y = ax^p \tag{4-3}$$

$$\sigma_z = bx^q \tag{4-4}$$

where a,b = empirical parameters.

Values of p and q depend on terrain roughness and atmospheric stability. Suggested values are listed in Table 4-2. Values of the plume rise parameter (K) depend on the characteristics of the stack. Equations for computing this parameter are listed in Table 4-3.

Table 4-2. VALUES OF DIFFUSION PARAMETERS BY STABILITY CLASS AND TERRAIN

Stability Class	Downwind Distance (m)	Rural Terrain			Urban Terrain		
		p	q	q/p	p	q	q/p
A	≤ 250	0.903	1.03	1.14			
	250-500	0.903	1.51	1.67			
	≥ 500	0.903	2.10	2.32			
B	≤ 1,000	0.903	0.986	1.09	0.745	1.14	1.53
	≥ 1,000	0.903	1.09	1.20	0.745	1.14	1.53
C	All distances	0.903	0.911	1.01	0.730	0.97	1.33
D	≤ 1,000	0.903	0.827	0.916	0.710	0.77	1.08
	1,000-10,000	0.903	0.636	0.704	0.710	0.77	1.08
	≥ 10,000	0.903	0.540	0.598	0.710	0.77	1.08
E	≤ 1,000	0.903	0.778	0.862	0.650	0.51	0.785
	1,000-10,000	0.903	0.587	0.650	0.650	0.51	0.785
	≥ 10,000	0.903	0.366	0.405	0.650	0.51	0.785
F	≤ 1,000	0.903	0.791	0.876	0.650	0.51	0.785
	1,000-10,000	0.903	0.510	0.565	0.650	0.51	0.785
	≥ 10,000	0.903	0.315	0.349	0.650	0.51	0.785

Table 4-3. PLUME RISE PARAMETERS BY TYPE OF STACK AND STABILITY CLASS

Type of Stack Exhaust*	Stability Class	Plume Rise Equation
Jet Plume	A through D	$K = u(\Delta H) = 3\, v_s\, d$
Buoyant Plume	A through D	$K = u(\Delta H) = 42\, A^{3/4}$, $A \leq 24\ m^3/sec$
		$= 66.4\, A^{3/5}$, $A > 24\ m^3/sec$
Jet Plume	E and F	$\Delta H_1 = 0.945 \left[\frac{T^3\, v_s^4\, d^4}{T_s^2\, u^2\, g(\frac{\delta\theta}{\delta z})}\right]^{1/6}$
		$\Delta H_2 = 4 \left[\frac{T^2\, v_s^2\, d^2}{4T_s\, g(\frac{\delta\theta}{\delta z})}\right]^{1/4}$ (use lower of ΔH_1 and ΔH_2. ΔH_2 represents the limiting case for calm or near calm conditions.)
Buoyant Plume	E and F	$\Delta H_1 = 2.4 \left[\frac{FT}{ug(\frac{\delta\theta}{\delta z})}\right]^{1/3}$
		$\Delta H_2 = 5F^{1/4} \left[\frac{g}{T}(\frac{\delta\theta}{\delta z})\right]^{-3/8}$ (use lower of ΔH_1 and ΔH_2)

* If uncertain whether exhaust is a jet or buoyant plume, compute both ways and use classification which gives the highest values.

(Continued)

Table 4-3. PLUME RISE PARAMETERS BY TYPE OF STACK AND STABILITY CLASS (Concluded)

K = plume rise parameter, m^2/sec

$A = v_s d^2 \left(\frac{T_s - T}{T_s}\right)$ = buoyancy parameter, m^3/sec

ΔH = plume rise, m

u = wind speed, m/sec

v_s = stack exit velocity, m/sec

d = stack exit diameter, m

T_s = stack exit temperature, °K

T = ambient air temperature, °K

$g = 9.8$ = acceleration due to gravity, m/sec^2

$\frac{\delta\theta}{\delta z}$ = vertical gradient of potential temperature, °K/m
(representative values are: 0.02 and 0.035 for stability classes E and F, respectively)

$F = 2.45\ v_s\ d^2 \left(\frac{T_s - T}{T_s}\right)$ = buoyancy flux, m^4/sec^3

Stack With Significant Plume Rise

The following procedures may be used to estimate the maximum ground-level concentration from a point source with known emission rate (Q) when the critical effective source height (H_{crit}) exceeds 10 m:

A. For stability classes A, B, C, and D:

1. Using H_{crit}, find $(\chi u/Q)_{max}$ and x_{max} from Figure 4-1 or 4-2. If x_{max} does not lie within the downwind distance range which corresponds to the selected q/p value, recompute H_{crit} and repeat this step with a new q/p value for another distance range.
2. Compute K from Table 4-3.
3. Compute x_{max}

$$x_{max} = \left(\frac{\chi u}{Q}\right)_{max} \frac{Qh}{K} \left(\frac{q}{p}\right) \qquad (4\text{-}5)$$

B. For stability classes E and F, plot χ_{max} as a function of wind speed to identify the peak χ_{max}. For each wind speed (u):

1. Compute ΔH from Table 4-3.
2. Compute $H = h + \Delta H$.
3. Find $(\chi u/Q)_{max}$ from Figure 4-1 or 4-2.
4. Compute $\chi_{max} = (\chi u/Q)_{max}\ Q/u$ for several values of u.
5. Plot χ_{max} as a function of u.

As a result of following procedures A and B above, a value of χ_{max} will be obtained for each stability class. For the highest χ_{max} there will be a corresponding wind speed, stability class and $(\chi u/Q)_{max}$. The distance downwind (x_{max}) at which this highest χ_{max} occurs can be read from Figure 4-1 or 4-2, whichever is appropriate.

The emission rate (Q) used in procedures A and B above should be the maximum which is likely to occur with each stability class. Since stability classes A, B, and C only occur during daylight hours and stability classes E and F only occur during nighttime hours, the maximum emission rate for each stability class will depend on the plant operating schedule. Plants which only operate during the day or auxiliary power plants which only operate during periods of peak load are examples of sources which have emission rates of zero for some stability classes. The maximum number of hours that each stability class may occur is dependent on the solar altitude, which varies with season, latitude and time of day. The maximum number of hours for various latitudes are shown in Table 4-4. The maximum number of hours for which stability classes A, B, and C occur will be centered on noon (or 1 p.m. for daylight saving time) during June. For stability classes E and F the maximum will be centered on midnight (or 1 a.m. daylight saving time) during December. Corrections to these values for other times of the year may be made by interpolation or by consulting references which treat solar altitude (e.g., List 1951).

Where several non-reactive pollutants are emitted from the same stack, the maximum short-term concentration (χ_1) of one is related to the

other (x_2) in direct proportion to the ratio of their emission rates (Q_1, Q_2):

$$x_2 = x_1 \frac{Q_2}{Q_1} \qquad (4\text{-}6)$$

For averaging periods greater than one hour, the maximum concentration at any one point will be reduced from the maximum one-hour concentration, even under steady meteorological conditions, due to the natural meander of the wind direction with time. The maximum concentrations for longer periods occur when the meteorological conditions and emission rates persist relatively unchanged for the length of the period of interest (e.g., 3, 8, or 24 hours). When this is a reasonable assumption, the correction factors shown in Table 4-5 will enable one to make a rough estimate of the maximum concentrations applicable for periods longer than one hour from the maximum one-hour concentration. These factors reflect normally observed diurnal variations in meteorological conditions and are most applicable to the ratio of the average concentration for a specific period to the maximum one-hour concentration during that period (Slade 1968, pp. 154-156).

When significant changes in either the emission rate or atmospheric stability or both are expected over the averaging period of interest, an alternate method of estimating the maximum concentration may be used. The period may be subdivided into sub-periods of relatively constant conditions. A one-hour maximum concentration should be calculated for each sub-period. By appropriately weighting the sub-period concentrations, a mean one-hour maximum concentration should be determined for the whole period of interest before the correction factors of Table 4-5 are applied. Changes associated with fumigation (discussed in a following section) should be included in this average, if appropriate. In deciding which of the preceding two methods are applicable in estimating 3-, 8- and 24-hour maximum concentrations from maximum one-hour concentrations,

Table 4-4. MAXIMUM DURATION OF STABILITY CLASSES FOR SELECTED LATITUDES AND DATES

Latitude	Date	Maximum Duration of Stability Class (Hours)*			
		A	B	C	E, F
30°N	Dec 22	0	2	7	16
	Feb 9, Nov 3	0	4	8	15
	Mar 8, Oct 6	0	6	9	14
	Apr 3, Sept 10	2	7	10	14
	May 1, Aug 12	4	8	11	13
	Jun 22	4	8	12	12
40°N	Dec 22	0	0	6	17
	Feb 9, Nov 3	0	1	7	16
	May 8, Oct 6	0	5	9	14
	Apr 3, Sept 10	0	6	10	13
	May 1, Aug 12	2	7	11	12
	Jun 22	4	8	12	11
50°N	Dec 22	0	0	2	18
	Feb 9, Nov 3	0	0	6	17
	Mar 8, Oct 6	0	1	8	15
	Apr 3, Sept 10	0	5	10	13
	May 8, Oct 6	2	7	11	11
	Jun 22	4	8	12	10

* Based on duration of solar angle above or below following limits: Class A - above 60°, Class B - above 35°, Class C - above 15°, Class E and F - below 0° plus two-hours.

consideration should be given to the persistence of the wind direction. For example, under unstable and/or light wind speeds the wind direction is not persistent and will vary greatly with time. In this case, the second method using subdivision of the period is appropriate. A persistent wind direction is usually associated with neutral stability and high wind speeds. In this case, the first method is appropriate.

Table 4-5. CORRECTION FACTORS FOR EXTENDING MAXIMUM 1-HOUR CONCENTRATIONS TO LONGER AVERAGING PERIODS

Averaging Period (Hours)	Rural	Urban
3	0.70	0.82
8	0.50	0.71
24	0.35	0.58

Stack with Little or No Plume Rise

The following steps may be followed to estimate the maximum concentration from a elevated source with little or no plume rise due to momentum or buoyancy effects.

A. For each stability class:

1. Using the source emission height, read the $(\chi u/Q)_{max}$ value from Figure 4-1 or 4-2.
2. Using the appropriate maximum emission rate and the minimum wind speed (u_{min}) for the times of day that the stability class occurs, estimate the maximum concentration as follows:

$$\chi = \left(\frac{\chi u}{Q}\right)_{max} \frac{Q_{max}}{u_{min}}$$

If calm winds occur with the stability class, u_{min} may be approximated as 1 m/sec.

B. If an averaging period longer than one-hour is of interest, the maximum one-hour concentration from Step 2 may be multiplied by the appropirate correction factor from Table 4-5 to estimate the maximum for a longer term period. If the emission rates of meteorological conditions are expected to undergo significant changes during the averaging period, it is appropirate to determine the maximum one-hour concentration as a weighted average of sub-periods before applying these correction factors. Step A may be repeated for each sub-period, and a mean one-hour concentration may be determined by multiplying the maximum concentration for each sub-period by the ratio of the length of the sub-period to the total averaging period and summing the resultant products for all sub-periods.

Mechanical tubulence around the stack can significantly alter the effective stack height by creating a downwash in the wake of the stack. This effect is especially pronounced when the stack gas exist velocity is low and when the wind speed is high. A method of estimating the effect when the downwash is created by a building is given in the methodology for emissions from a roof or the side of a building. As a general rule whenever the stack height is less than 2.5 times the height of the highest building adjacent to the stack, aerodynamic downwash effects will be present to some degree.

Emissions from a Rooftop or Side of a Building

When emissions are released from a vent, short stack or other type of portal on top or on the side of a building, the emissions will become trapped in the turbulent cavity immediately downwind of the building. The maximum concentration is given by the following simple volume approximation (Smith 1968).

$$\chi = \frac{Q_{max}}{CAu_{min}} \qquad (4\text{-}7)$$

where χ = maximum concentration downwind of the building, $\mu g/m^3$

Q_{max} = maximum emission rate, $\mu g/sec$

C = shape factor

A = minimum crosswind area of the building, m^2

u_{min} = minimum wind speed (not less than 1), m/sec.

The shape factor (C) probably ranges from 0.5 for a streamlined shape to 2.0 for the common bluff shaped building. The results of Equation 4-7 may be modified using wind direction frequencies to approximately account for meandering effects of the wind for averaging periods in excess of one-hour.

Ground Level Source

The maximum concentration from ground level sources will occur in the immediate vicinity of the source and will be very high. Exposure to these concentrations can be avoided by preventing access to areas within critical distances of the source. For a specified minimum approach distance (e.g., distance to the edge of the property on which the source is located) the maximum relative concentration ($\chi u/Q$) for each stability class is given in Figure 4-3 for rural terrain and in Figure 4-4 for urban terrain. Using these values, the appropriate maximum emission rate (Q_{max}) and the minimum wind speed (u_{min}) for the times of the day that each stability class occurs, estimate the maximum concentration as follows:

$$\chi = \left(\frac{\chi u}{Q}\right) \frac{Q_{max}}{u_{min}}$$

If calm winds occur with a stability class, u_{min} may be approximated as 1 m/sec.

If an averaging period longer than one-hour is of interest, the maximum one-hour concentration may be multiplied by the appropriate correction factor from Table 4-5 to estimate the maximum for the longer term period. If the emission rates or meteorological conditions change significantly over the averaging period, a mean one-hour maximum concentration may be determined as a weighted average of sub-periods before the correction factors are applied.

Fumigation from Stacks with Significant Plume Rise

The preceding methods of analysis have dealt with the dispersion of pollutants into a layer with a well-defined stability which extends from well above the effective stack height to ground level. In addition, consideration

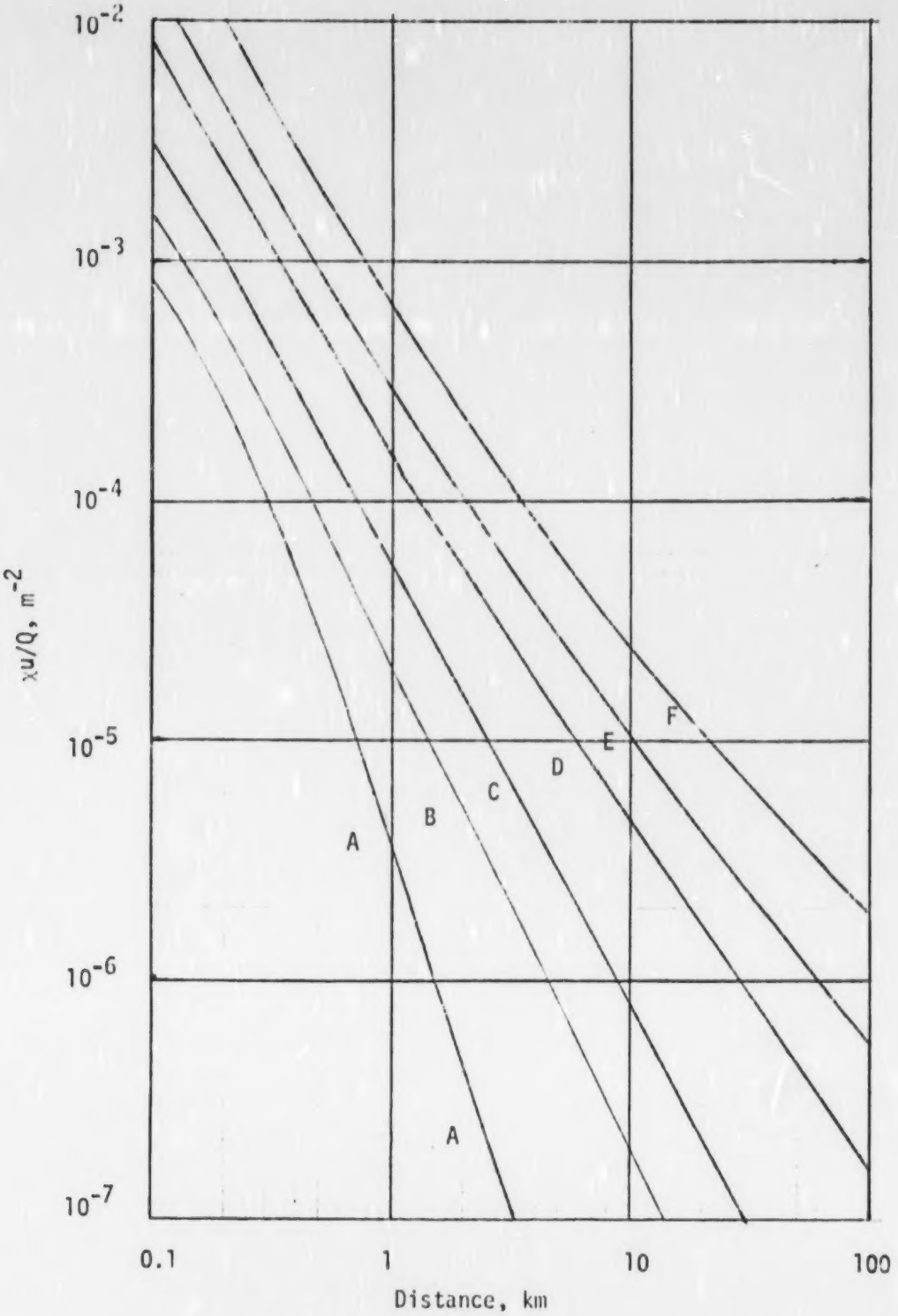

Figure 4-3. Maximum χu/Q as a Function of Downwind Distance and Stability Class Over Rural Terrain

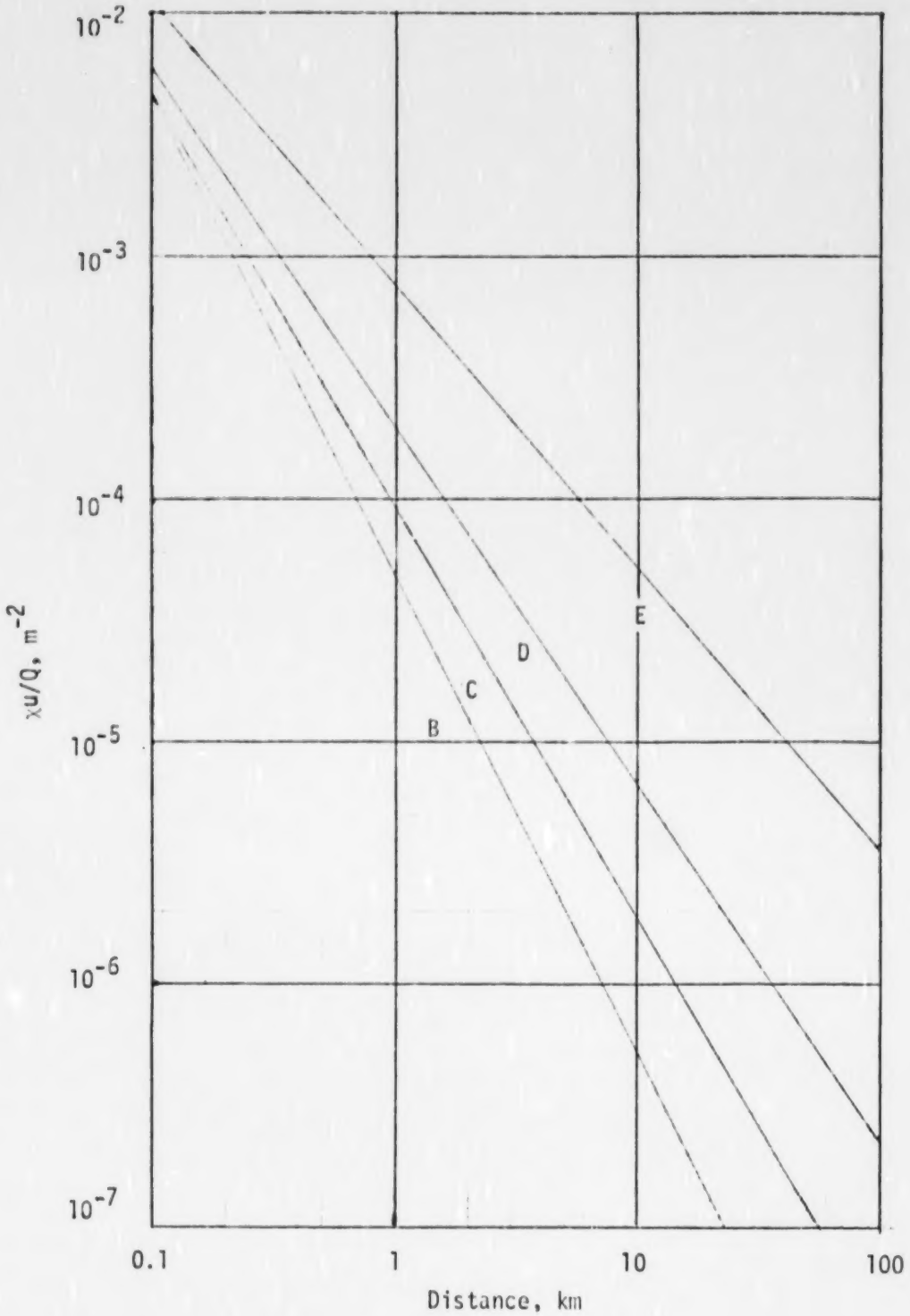

Figure 4-4. Maximum χu/Q as a Function of Downwind Distance and Stability Class Over Urban Terrain

must be given to the high ground level concentrations which exist due to a phenomenon known as fumigation. Fumigation occurs as a result of the break up of a stable layer by heating of the ground surface. Pollutants emitted into the stable layer are mixed vertically by thermal eddies resulting in higher than normal ground level concentrations. Typical situations in which fumigation occurs are:

- "Burning off" of the nocturnal radiation inversion by solar warming of the ground surface
- Advection of pollutants from a stable rural environment to a turbulent urban environment
- Advection of pollutants from a stable environment on or near water to an unstable inland environment.

The maximum fumigation concentration may be approximated by the following equation (Turner 1970):

$$\chi_F = \frac{Q}{\sqrt{2\pi}\, u(\sigma_y + H/8)\,(H + 2\sigma_z)} \qquad (4\text{-}8)$$

where χ_F = maximum fumigation concentration

Q = emission rate

u = wind speed in stable layer

σ_y = horizontal diffusion parameter for stable conditions (see Figure 4-5)

σ_z = vertical diffusion parameter for stable conditions (see Figure 4-6)

$H = h + \Delta H$ = effective source height

h = stack height

ΔH = plume rise for <u>stable</u> conditions (see Table 4-3).

Values of σ_y and σ_z for the nearest downwind distance (x) at which fumigation effects will occur due to "burning off" of the nocturnal radiation inversion may be estimated by a method suggested by Hewson (1945):

$$x = \frac{u\,[(H + 2\sigma_z)^2 - h^2]}{4K} \qquad (4\text{-}9)$$

where K = eddy diffusivity for heat ≈ 3 m^2/sec (Hewson 1945).

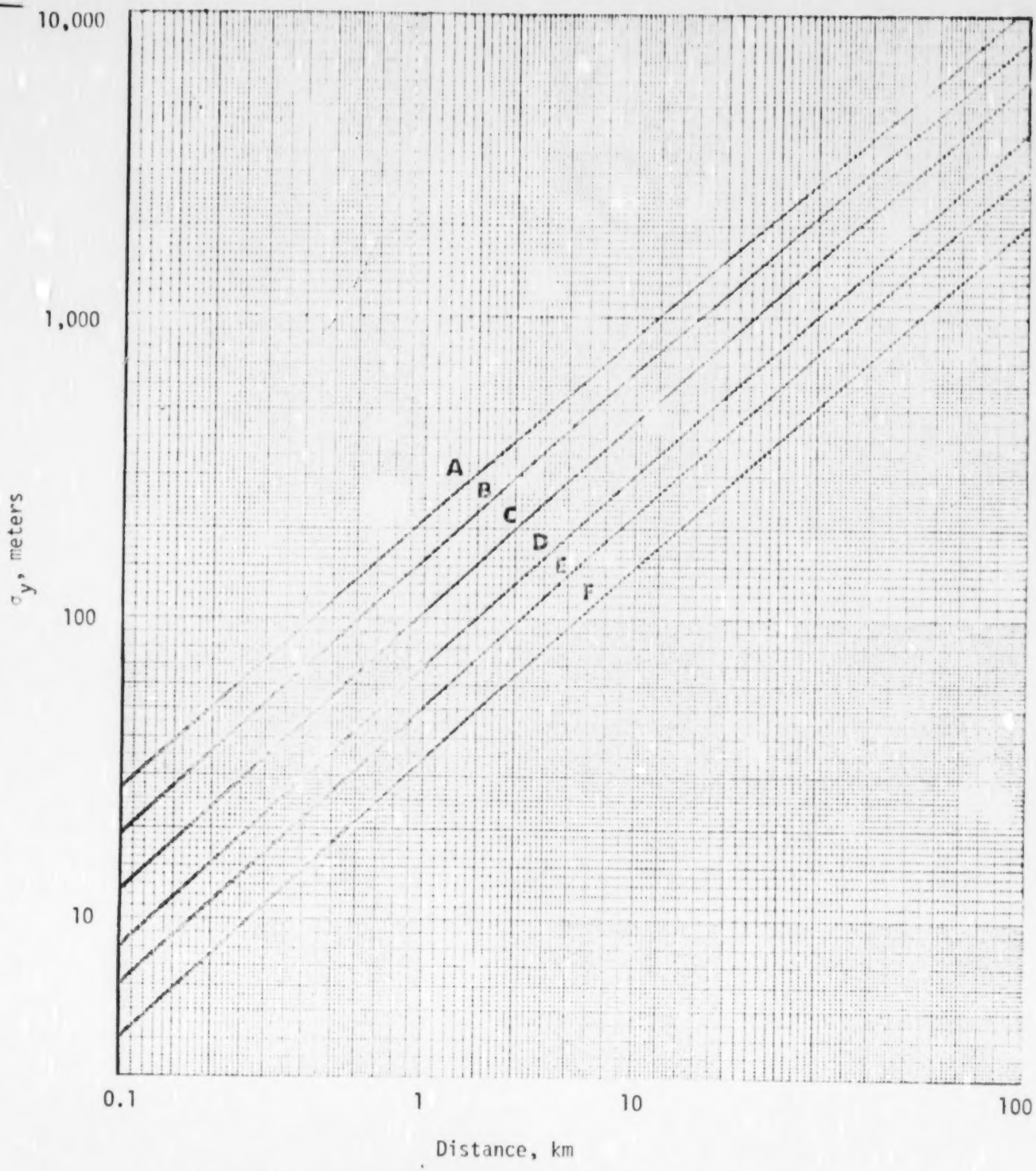

Figure 4-5. Horizontal Diffusion Parameter (σ_y) as a Function of Downwind Distance and Stability Class Over Rural Terrain

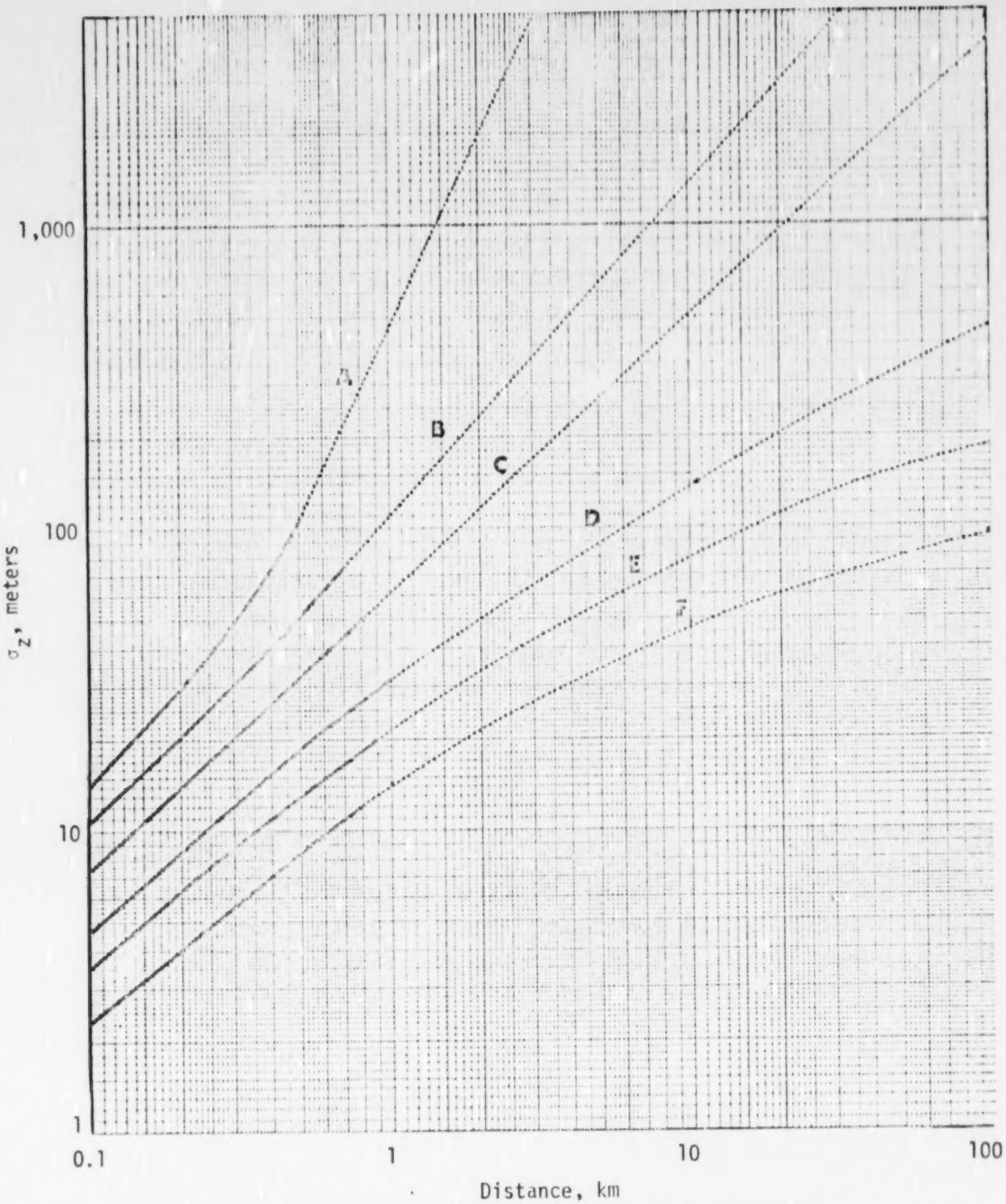

Figure 4-6. Vertical Diffusion Parameter (σ_z) as a Function of Downwind Distance and Stability Class Over Rural Terrain

Solutions to this equation may be obtained by graphical solution by plotting $h^2 + 12x/u$ and $(H + 2\sigma_z)^2$ as functions of x. The solution is given by the intersection of the two lines.

When the pollutants are advected from a stable environment to a turbulent one, the distance x will have to be estimated on the basis of geographic considerations or observations of where the turbulent effects begin.

ANNUAL MEAN CONCENTRATIONS FROM A POINT SOURCE

Two methods are presented here for estimating annual mean concentrations from a point source. The first method is applicable to a source that emits at a nearly constant emission rate from hour to hour and day to day. The second method requires many more calculations and is applicable to a source with varying emission rates. Both methods require a large number of calculations to get a desirable degree of spatial resoultion of the annual mean concentrations and are appropriately executed by means of a computer program. However, in addition to the methodology for a complete set of calculations, suggestions are included for estimating by hand: (1) the location and value of the highest annual mean concentration, and (2) the contribution of the source to the annual mean concentration in critical areas.

Constant Emission Rate

For sources which operate more or less continuously 24 hours a day with relatively constant emissions, the following equations provide an estimate of the annual mean concentration $\chi(x,\theta)$ at a distance x from the source along an azimuth θ, where θ is one of 16 possible wind directions. If $(\sigma_z)_i \leq 0.8L_i$,

$$\chi(x,\theta) = \sum_{j=1}^{N_j} \sum_{i=1}^{N_i} \frac{2.03Q\, f_{i,j}^{(\alpha)}}{(\sigma_z)_i\, u_j\, x} \exp\left\{ -\frac{1}{2}\left[\frac{H_{ij}}{(\sigma_z)_i}\right]^2 \right\} \qquad (4\text{-}10)$$

If $(\sigma_z)_i > 0.8L_i$,

$$\chi(x,\theta) = \sum_{j=1}^{N_j} \sum_{i=1}^{N_i} \frac{2.55Q\, f_{i,j}(\alpha)}{L_i u_j x} \qquad (4\text{-}11)$$

where

Q = emission rate, µg/sec

$(\sigma_z)_i$ = vertical diffusion parameter for stability class i and distance x, m

u_j = mean wind speed for class j, m/sec

$f_{i,j}^{(\alpha)}$ = relative frequency of occurrence of stability class i and wind speed class j with wind direction blowing from α and toward θ (i.e., $\theta = \alpha \pm 180°$)

$H_{i,j}$ = effective source height (including stack height plus plume rise) for stability class i and wind speed class j, m

L_i = height of the mixing layer for stability class i, m.

Equations 4-10 and 4-11 may be usefully applied when the joint frequency distribution of wind direction, wind speed and atmospheric stability are known (i.e., frequently referred to as stability wind rose data). It may be noted in the above equation that the sum (F_α) of the $f_{i,j}^{(\alpha)}$ values will be the frequency that the wind direction α is expected to occur, which must be a fraction between zero and one. By repeating equations 4-10 and 4-11 for a sufficient number of values of x and for all values of θ, one can obtain the spatial distribution of annual mean concentrations from the source.

A standard joint frequency distribution of wind direction, wind speed and atmospheric stability classes may be obtained from the National Climatic Center (NCC) of the National Oceanic and Atmospheric Administration, Asheville, North Carolina. Compilations are already available for many locations or can be generated using specified years of meteorological

data by menas of the NCC STAR computer program. The standard joint frequency distributions available from NCC consist of 576 entries, including 16 wind directions, the six Pasquill stability classes, and the six wind speed classes shown in Table 4-6. There are two other options available for the stability classes: 5 stability classes (E and F combined); 6 stability classes, including A, B, C, D (day only), D (night only) and E (combined with F).

Table 4-6. WIND SPEED CLASSES USED BY NCC FOR JOINT FREQUENCY DISTRIBUTION OF WIND SPEED, WIND DIRECTION AND STABILITY

Class	Speed Interval, m/sec (Knots)	Class Mean, m/sec
1	0 to 1.8 (0 to 3)	1.50
2	1.8 to 3.3 (4 to 6)	2.46
3	3.3 to 5.4 (7 to 10)	4.47
4	5.4 to 8.5 (11 to 16)	6.93
5	8.5 to 10.8 (17 to 21)	9.61
6	>10.8 (>21)	12.52

The effective source height $H_{i,j}$ may be adjusted to account for irregularities of terrain as well as to reflect the effects of the stack height and the plume rise.

$$H_{i,j} = h + \Delta H_{i,j} + Z_s - Z_r$$

where h = stack height

$\Delta H_{i,j}$ = plume rise (see Table 4-3; note that $\Delta H_{i,j} = K/u_j$ for stability classes A, B, and D)

Z_s = elevation of source (base of stack)

Z_r = elevation of point with coordinates (x,θ).

Except where major terrain variations are present due to valleys and hills, Z_s and Z_r should be taken to be equal. Negative values and small positive values are not meaningful for $H_{i,j}$ when these result from large values of Z_r. It is recommended that a minimum value of H = 10 m be used.

Values of $(\sigma_z)_i$ for various travel distances (x), stability classes i and two types of terrain (rural and urban) may be obtained from the following equation or from Figure 4-6 for rural terrain.

$$(\sigma_z)_i = a_i \, x^{b_i} \qquad (4\text{-}12)$$

Values of the parameters a_i and b_i are listed in Table 4-7. Values of the height of the mixing layer L_i may be estimated using the values listed in Table 4-7. Annual mean afternoon mixing heights (L_a) as estimated by Holzworth (1972) are shown in Figure 4-7 for the contiguous United States. Annual mean morning mixing heights are shown in Figure 4-8. These were determined as the height of the intersection of the dry adiabatic temperature corresponding to the morning minimum surface temperature plus 5°C with the vertical temperature profile observed at 1200 Greenwich Median Time. This may be used as the nocturnal urban mixing layer height (L_n) if other information is not available. The effective source height $H_{i,j}$ may be calculated using the equations in Table 4-3, the stack characteristics, a representative mean ambient air temperature (the plume rise equations are not very sensitive to the normal range of ambient air temperatures), and an estimate of the vertical temperature gradient. If other information is not available for the vertical temperature gradient, use 0.02°K/m for class E and 0.035°K/m for class F.

The methodology represented by Equations 4-10 and 4-11 includes the limited mixing effects which result from the presence of a finite, ground-based mixing layer. The methodology is most applicable when the effective stack height ($H_{i,j}$) is less than about one-fourth of the height of the mixing layer (L_i). To cover cases where the effective stack height is significantly greater than this, a more complex expression is applicable in place of Equation 4-10 (e.g., Turner 1970, p. 36).

Table 4-7. PARAMETRIC VALUES FOR VERTICAL DIFFUSION $(\sigma_z)_i$ AND HEIGHT OF THE MIXING LAYER (L_i)

Stability Class	Rural Terrain for Indicated Distances (X) (Busse and Zimmerman 1973)						Urban Terrain (Johnson et.al 1971)		Mixing Height Estimate*	
	100 to 500m		500 to 5000 m		5000 to 50,000m					
	a_i	b_i	a_i	b_i	a_i	b_i	a_i	b_i	Rural	Urban
A	0.0383	1.2812	0.2539×10^{-3}	2.0886	-	-	0.07	1.28	1.5 L_a	1.5 L_a
B	0.1393	0.9467	0.4936×10^{-1}	1.1137	-	-	0.12	1.14	L_a	L_a
C	0.1120	0.9100	0.1014	0.9260	0.1154	0.9109	0.23	0.97	L_a	L_a
D	0.0856	0.8650	0.2591	0.6869	0.7368	0.5642	0.50	0.77	L_a	L_a
E	0.0818	0.8155	0.2527	0.6341	1.2969	0.4421	1.35	0.51	L_a**	L_n
F	0.0545	0.8124	0.2017	0.6020	1.5763	0.3606	1.35	0.51	L_a**	L_n

* L_a is the annual mean afternoon mixing height. L_n is the annual mean nocturnal mixing height during stable conditions in urban areas.

** In a rural environment the mixing layer disappears entirely during night time stable hours. Use of L_a generally results in little constraint to vertical diffusion during stable conditions.

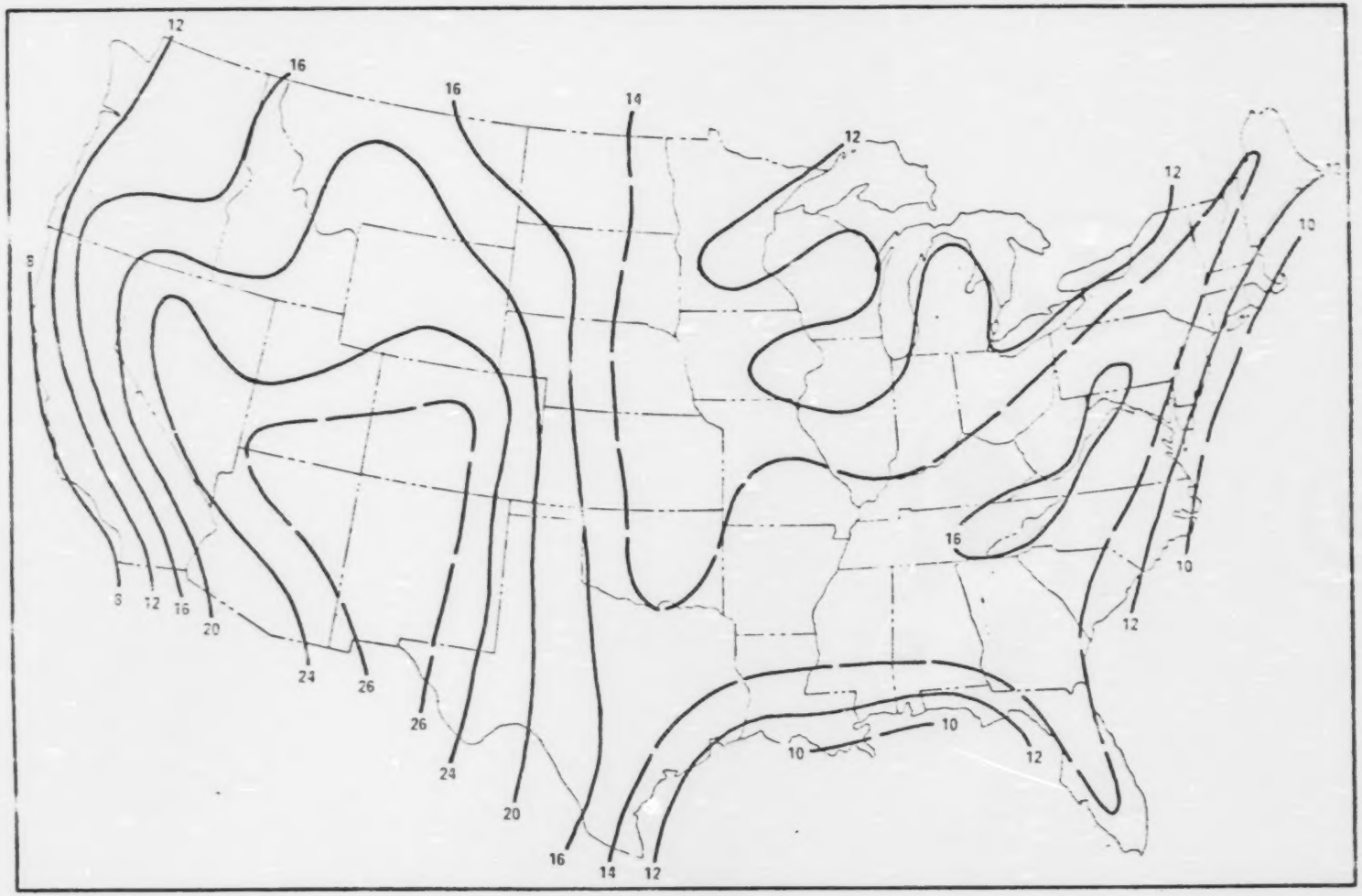

Figure 4-7. Isopleths (100's of meters) of Mean Annual Afternoon Mixing Heights (Holzworth 1972)

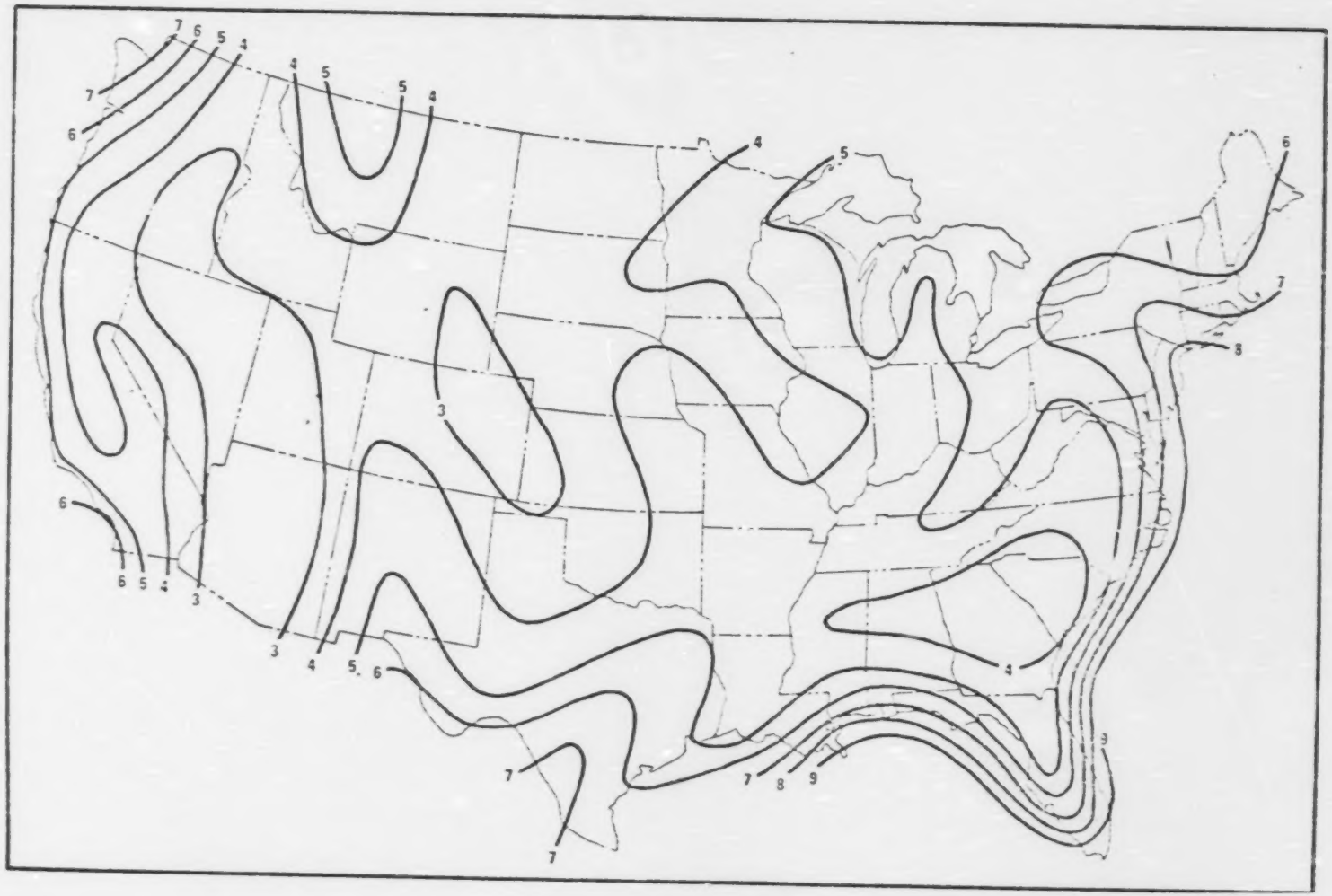

Figure 4-8. Isopleths (100's of meters) of Mean Annual Morning Mixing Heights (Holzworth 1972)

MAXIMUM SHORT-TERM CONCENTRATIONS AT CRITICAL LOCATIONS

Frequently the concentrations from a new source which are most critical in evaluating its impact, are those which occur at locations which are already exposed to high concentrations from other sources. These locations will be known to air quality control agencies on the basis of air monitoring and simulation modeling activities. The contribution of a new source to the annual mean concentration at critical locations a distance x in direction θ from the new source can be estimated using Equations 4-10 and 4-11. It may be noted that both Equations 4-10 and 4-11 may be required to estimate the annual mean concentration for the location of interest. In applying Equation 4-10, the criterion $(\sigma_z)_i \leq 0.8L_i$ may not be satisfied for some of the N_i stability classes. In this case the terms for this stability class would be eliminated in the summation designated by Equation 4-10. These terms would occur in the summation designated by Equation 4-11. When both Equations 4-10 and 4-11 are used the resultant annual mean concentration is the sum of the concentration from Equations 4-10 and 4-11.

In order to evaluate the effect of the new source on critical short-term concentrations of pollutants, one needs to determine the meteorological conditions associated with the occurrence of critical short-term concentrations. If the associated wind directions conduct pollutants from the new source away from the critical locations, then contributions from the new source will be negligible. The associated wind directions may be determined by obtaining wind direction observations for all periods with measured critical short-term concentrations. Multiple-source diffusion models for simulating regional air quality levels may also be used to identify wind directions associated with critical air quality levels. If a well defined pattern of associated wind directions cannot be determined from the available data, an air pollution meteorologist should be consulted in determining what wind directions may be associated with critical

short-term concentrations. Although wind direction is generally the most significant associated meteorological condition, other associated conditions should be determined, including wind speeds, stability classes, times of day and times of the year.

The following information should be determined for locations with critical short-term concentrations:

- Coordinates of a representative exposure location in a critical area
- Range of critical short-term concentrations for this location (averaged over a time period which corresponds to an air quality standard for the pollutant of concern)
- Range of associated wind directions
- Range of associated wind speeds
- Range of associated stability classes
- Range of associated times of year
- Range of associated times of day.

Four methods follow for estimating the contribution of a new source to critical locations which are identified as having high short-term concentrations, when the azimuth from the critical location to the new source is within the range of associated wind directions. All four methods require the use of the following two items:

- Distance from new source to critical location

$$x = \left[(X_S - X_R)^2 + (Y_S - Y_R)^2\right]^{1/2} \qquad (4\text{-}13)$$

where X_S = East-West coordinate of source location
Y_S = North-South coordinate of source location
X_R = East-West coordinate of critical location
Y_R = North-South coordinate of critical location

- Maximum emission rate (Q_{max}) for associated times of day and times of year

Short-Term Concentration at Critical Locations, No Plume Rise

The following steps should be followed.

1. Using the distance given by Equation 4-13, the effective emission height, and the appropriate type of terrain (urban or rural), determine $\chi u/Q$ for all stability classes associated with critical concentrations from Figures 4-9 through 4-18. If rough terrain is present, major differences in the height of the source and the height of the critical location may be accounted for by modifying the effective plume height as follows:

$$H = h + Z_S - Z_R \qquad (4\text{-}14)$$

where H = height of source plume above critical location
h = effective emission height
Z_S = elevation of source
Z_R = elevation of critical location

The above correction procedure should only be used where major terrain variations due to hills and valleys are present. It must be noted that negative values and small positive values are not meaningful for H as a result of Equation 4-14. In situations leading to such results, the whole plume will be displaced vertically upward. It is recommended that a minimum value of H = 10 meters be used. An appropriate mixing height (L) can be determined using the suggestions in Table 4-7 and the values shown in Figure 4-7 and 4-8.

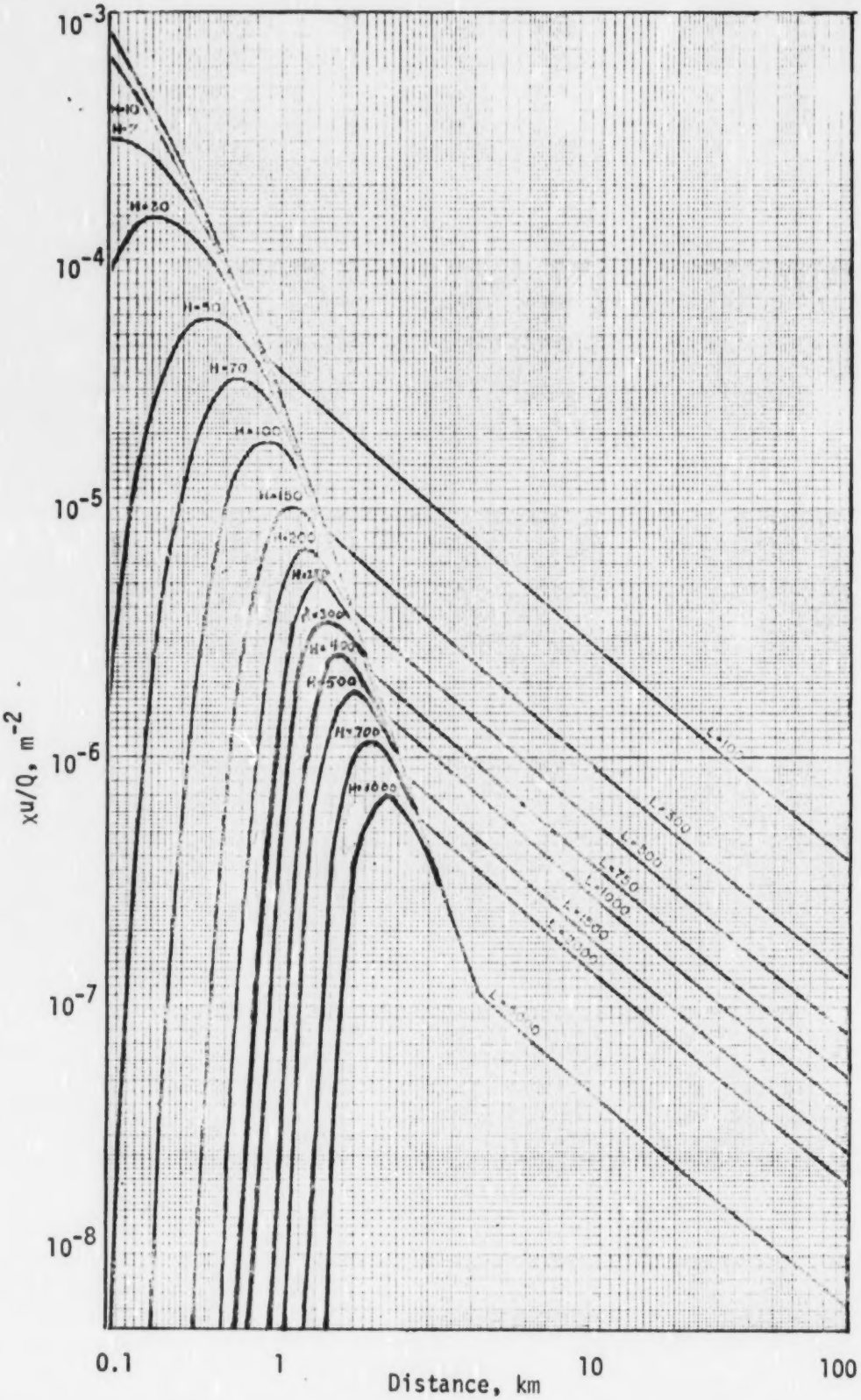

Figure 4-9. χu/Q with Distance for Various Heights of Emission (H) and Limits to Vertical Dispersion (L), A Stability and Rural Terrain

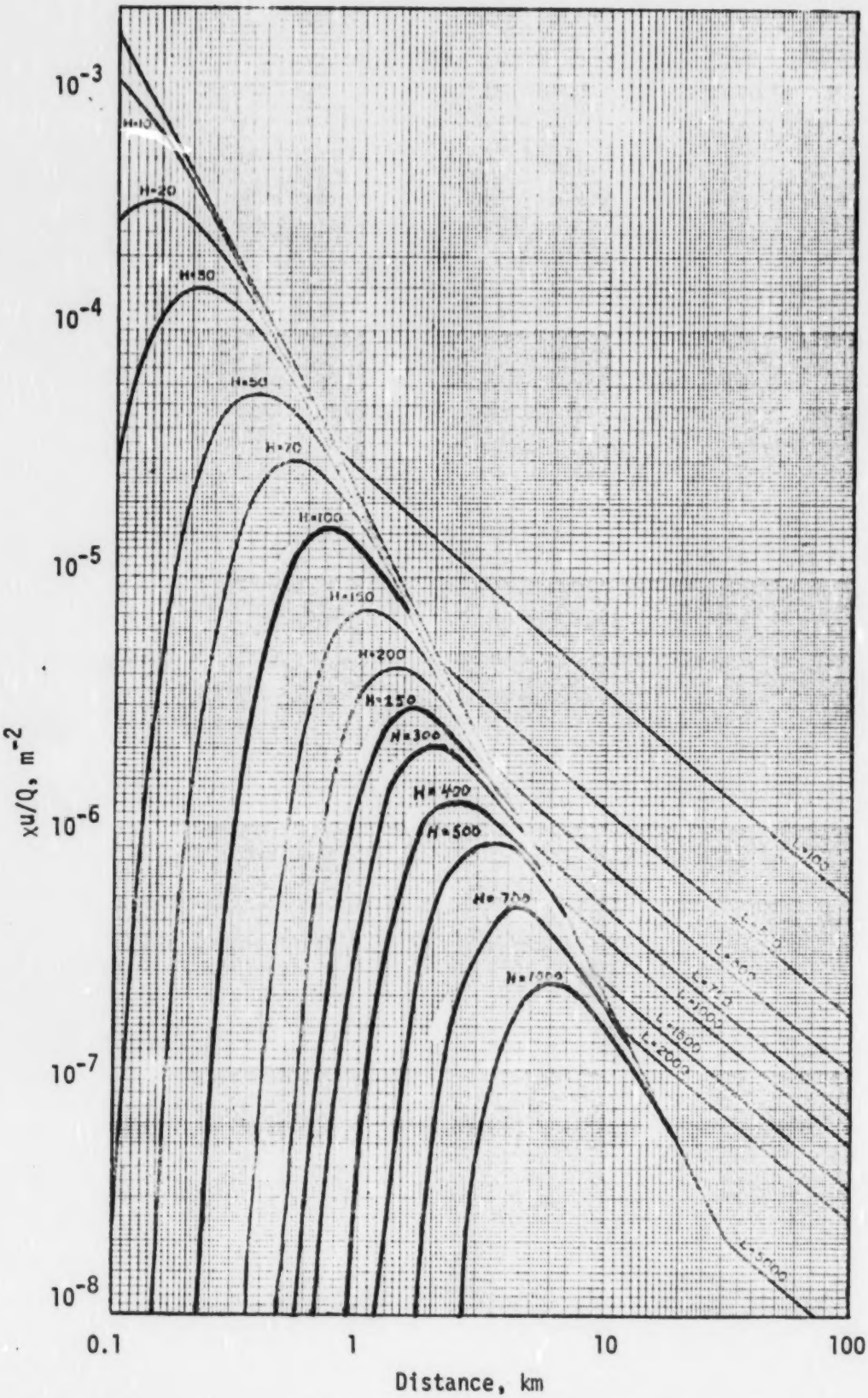

Figure 4-10. χu/Q with Distance for Various Heights of Emission (H) and Limits to Vertical Dispersion (L), B Stability and Rural Terrain

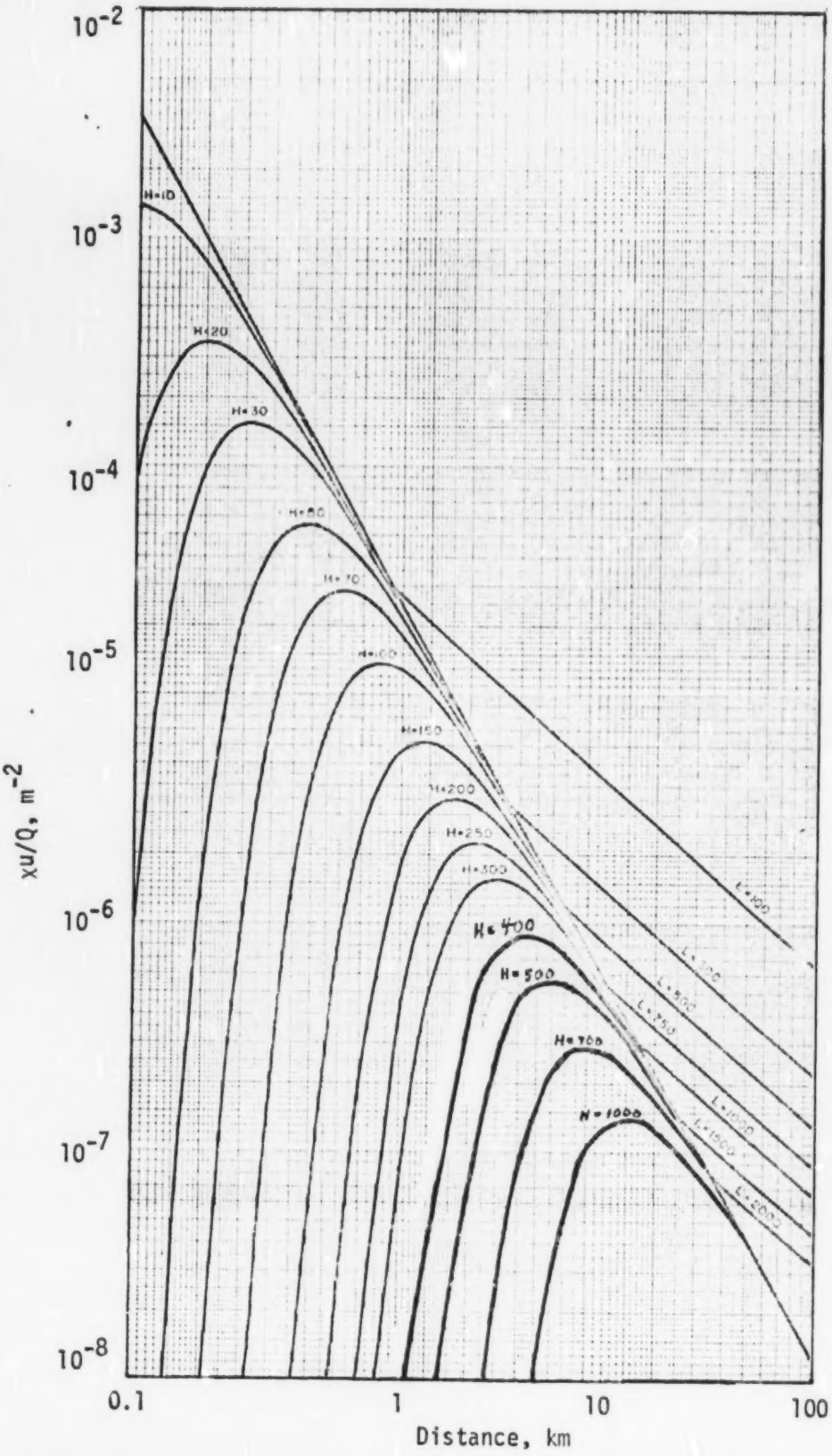

Figure 4-11. χu/Q with Distance for Various Heights of Emission (H) and Limits to Vertical Dispersion (L), C Stability and Rural Terrain

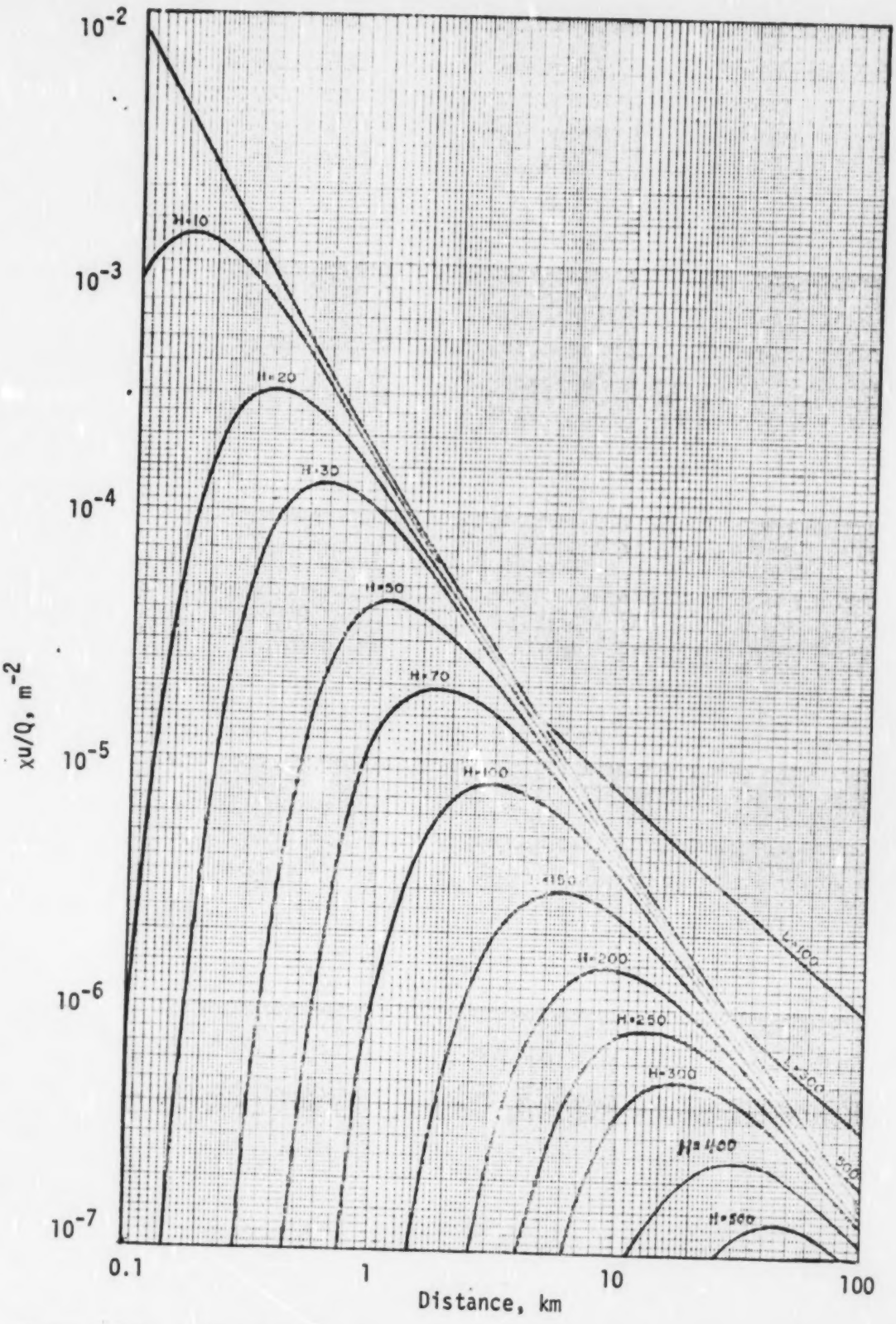

Figure 4-12. χu/Q with Distance for Various Heights of Emission (H) and Limits to Vertical Dispersion (L), D Stability and Rural Terrain

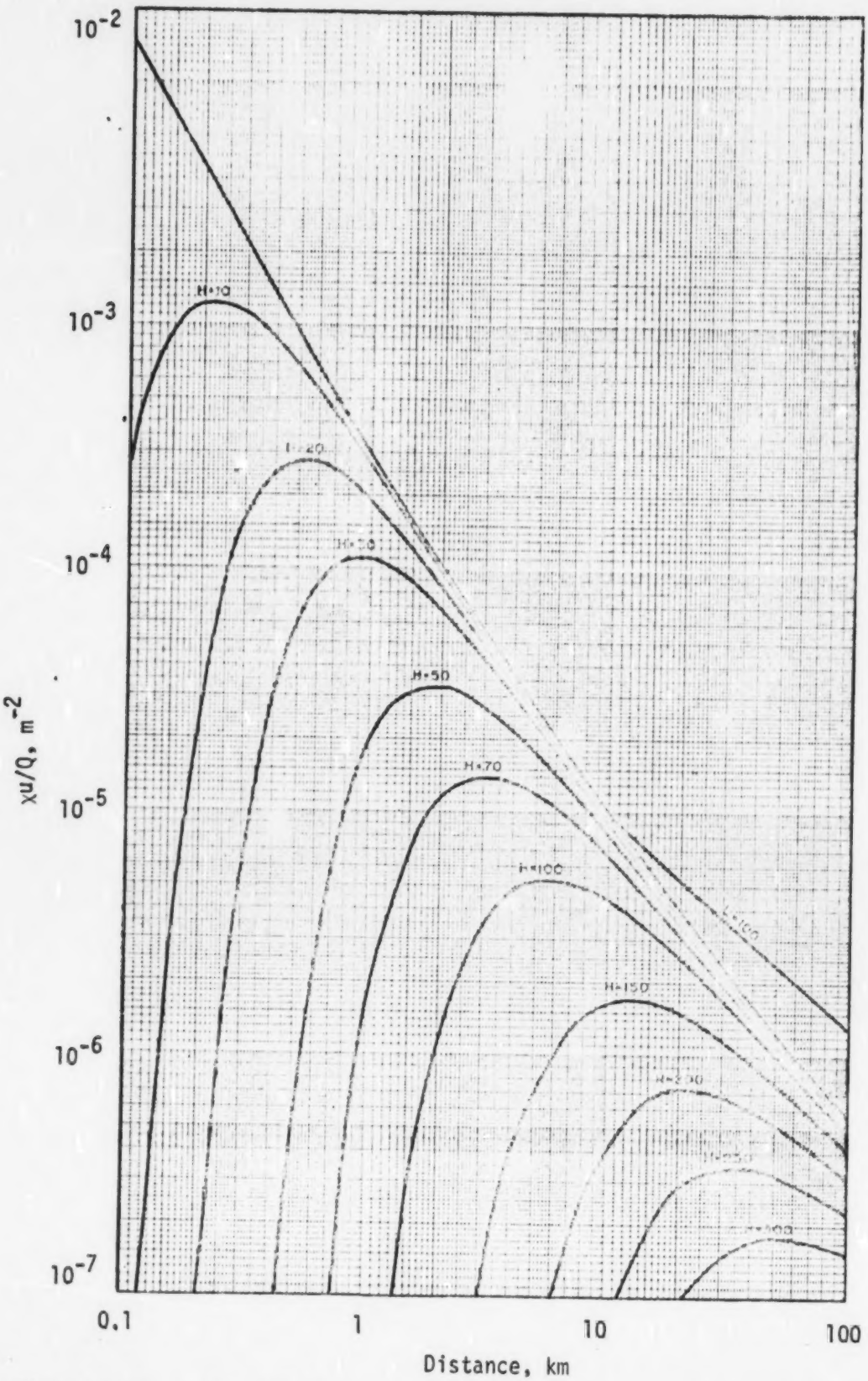

Figure 4-13. xu/Q with Distance for Various Heights of Emission (H) and Limits to Vertical Dispersion (L), E Stability and Rural Terrain

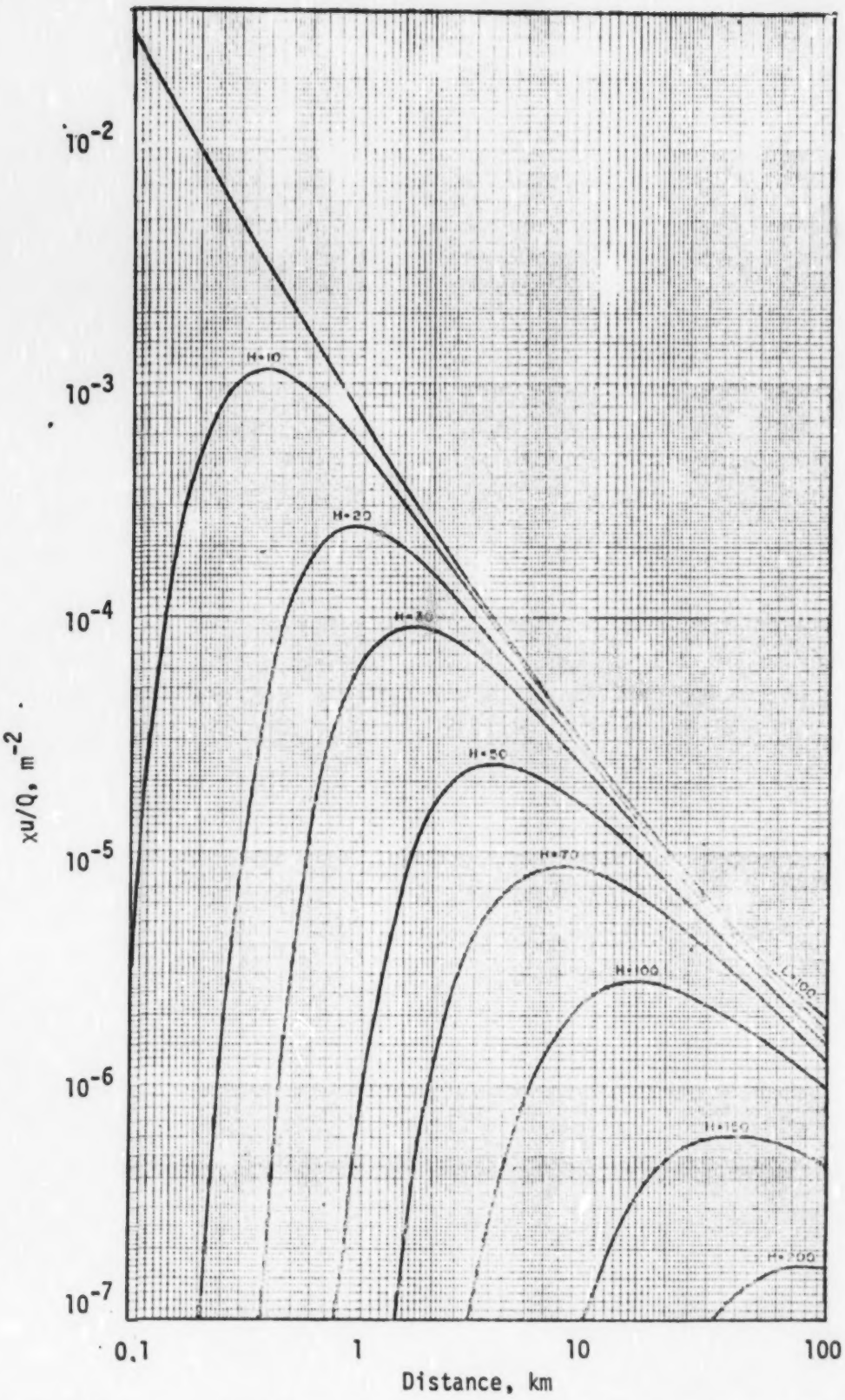

Figure 4-14. χu/Q with Distance for Various Heights of Emission (H) and Limits tc Vertical Dispersion (L), F Stability and Rural Terrain

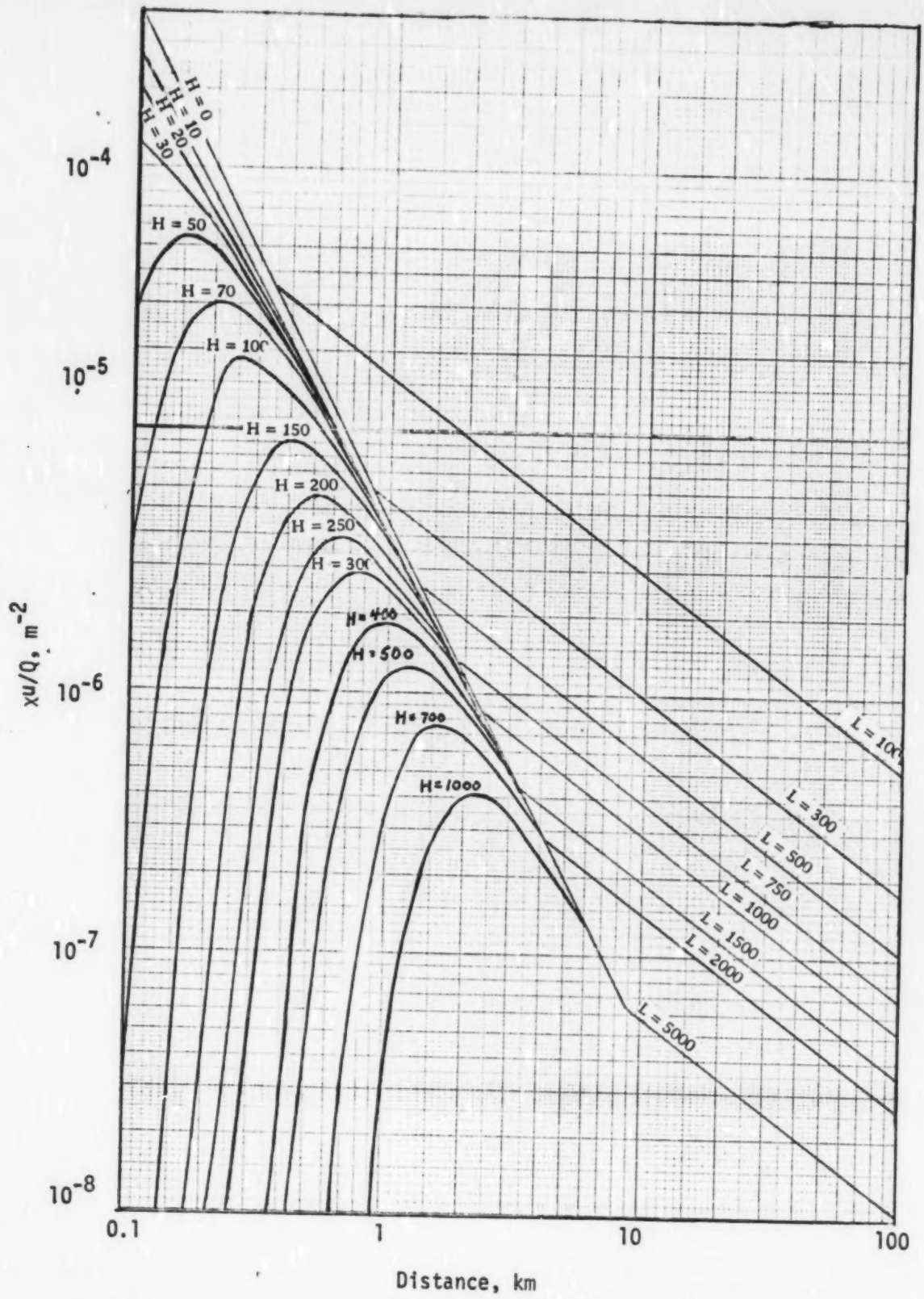

Figure 4-15. $\chi u/Q$ with Distance for Various Heights of Emission (H) and Limits to Vertical Dispersion (L), A and B Stability for Urban Terrain

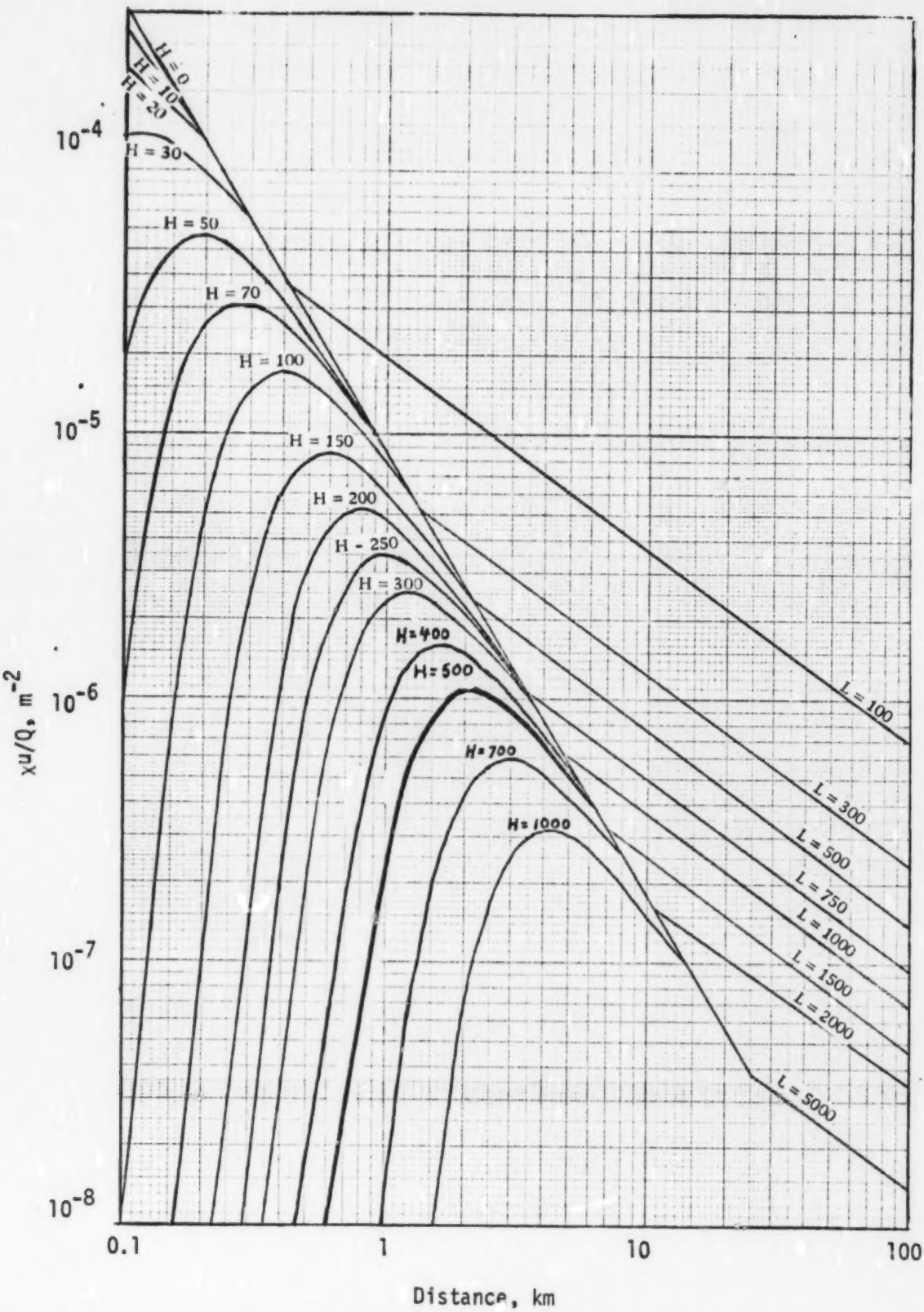

Figure 4-16. χu/Q with Distance for Various Heights of Emission (H) and Limits to Vertical Dispersion (L), C Stability for Urban Terrain

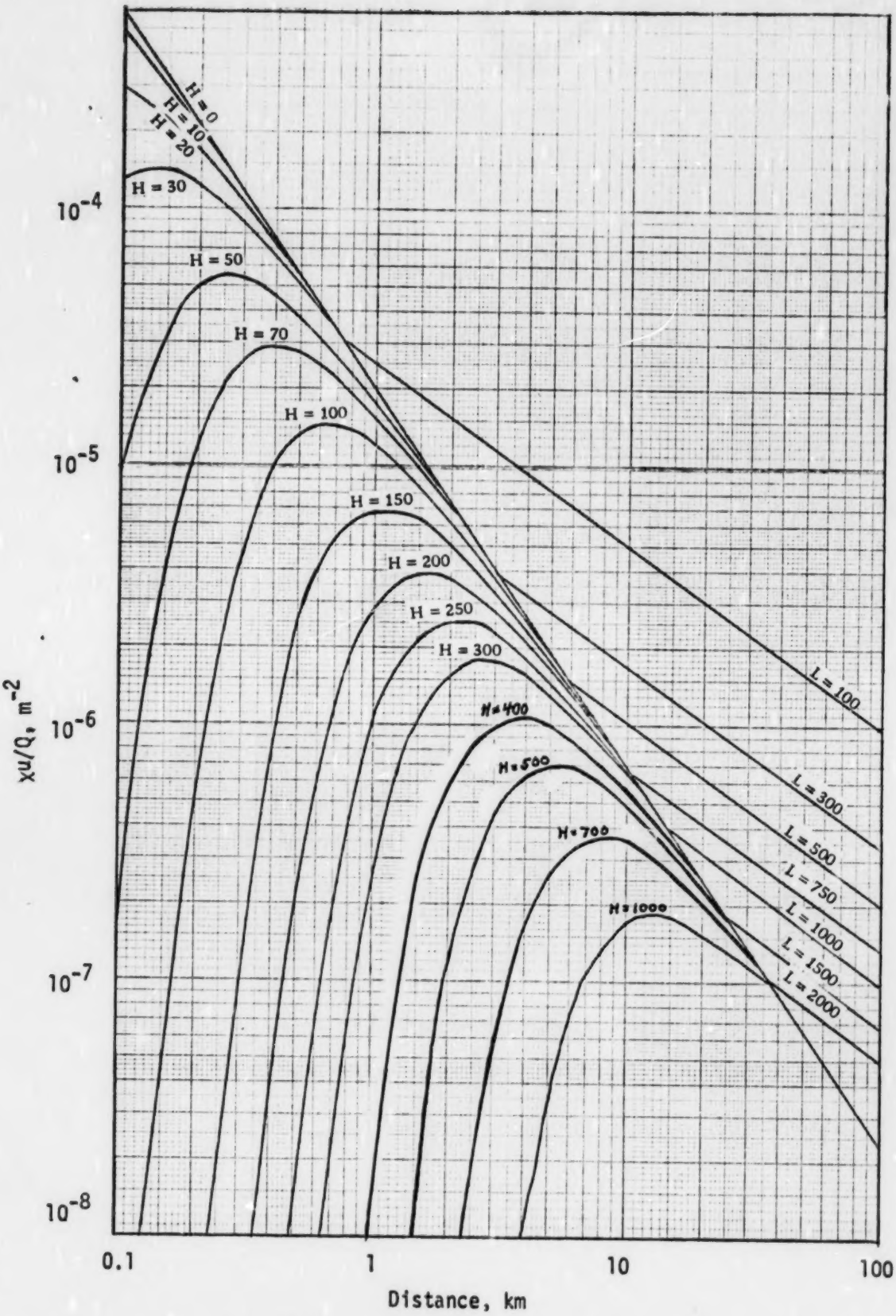

Figure 4-17. $\chi u/Q$ with Distance for Various Heights of Emission (H) and Limits to Vertical Dispersion (L), D Stability for Urban Terrain

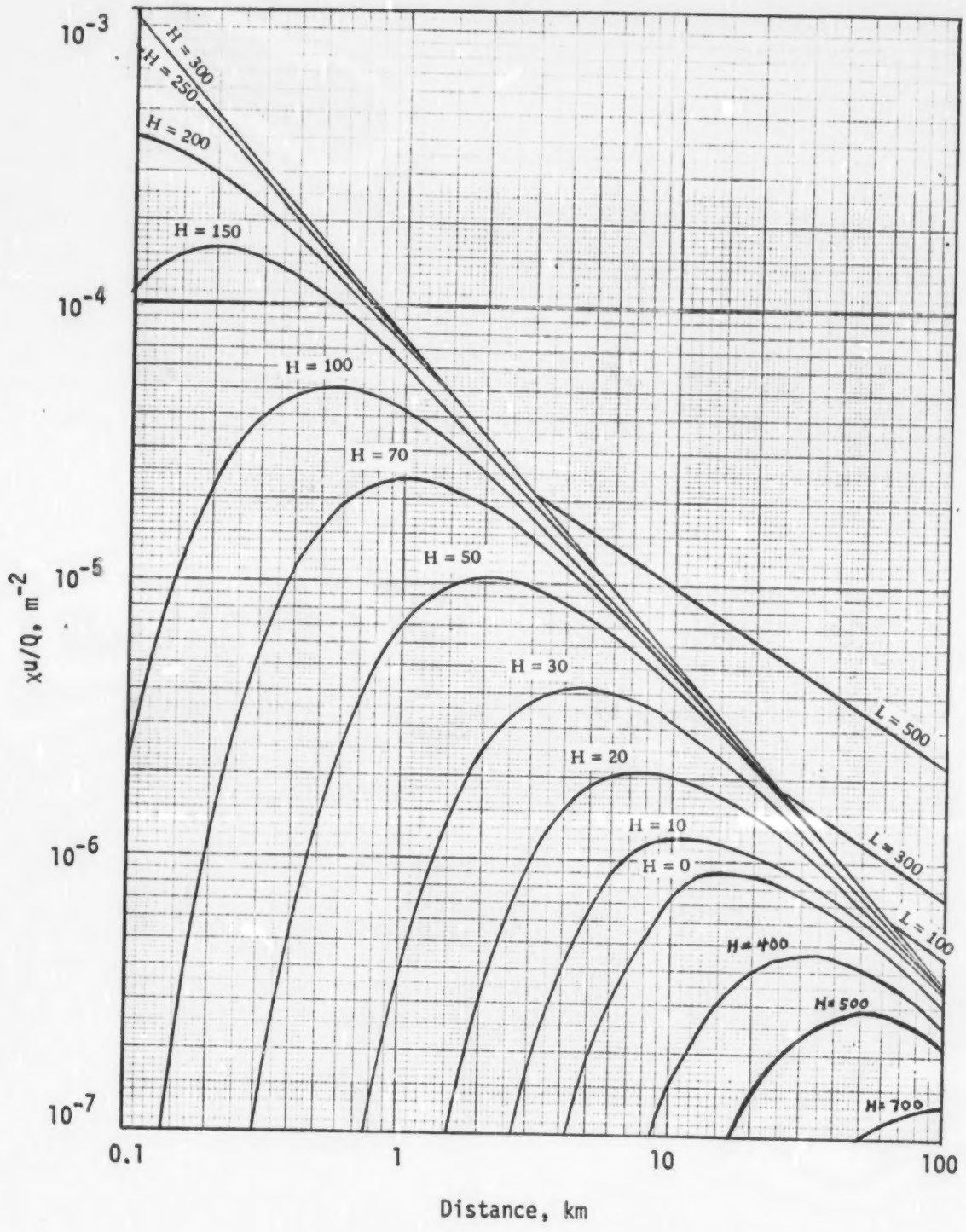

Figure 4-18. χu/Q with Distance for Various Heights of Emission (H) and Limits to Vertical Dispersion (L), E Stability for Urban Terrain

2. Using the maximum $\chi u/Q$ from step 1, the minimum wind speed (u_{min}) associated with critical concentrations and the appropriate maximum emission rate (Q_{max}), the maximum contribution from the new sources is given by

$$\chi = \left(\frac{\chi u}{Q}\right) \frac{Q}{u_{min}} \qquad (4\text{-}15)$$

Short-Term Concentration at Critical Locations With Plume Rise, Neutral and Unstable Conditions

For each neutral and unstable class of conditions associated with critical concentrations the following steps should be used to identify which class results in the maximum contribution from the new source.

1. Estimate the critical wind speed.

$$u_{crit} = \frac{K}{h\ (\frac{q}{p})} \qquad (4\text{-}16)$$

Values of q/p are listed in Table 4-2 for various combinations of terrain, travel distance and stability class. The travel distance of interest is given by Equation 4-13. If the u_{crit} value calculated using Equation 4-16 is outside the range of wind speeds associated with the critical concentrations, u_{crit} should be redefined as the value within this range which is closest to the value given by Equation 4-16.

2. Using the new source stack height (h), estimate the effective source height (H).

$$h + \frac{K}{u_{crit}} \qquad (4\text{-}17)$$

This estimate may be further modified to account for the effects of rough terrain by adding the source elevation and subtracting the critical location elevation. See the discussion following Equation 4-14.

3. Using the source to receptor travel distance from Equation 4-13, the effective source height from step 1 and mixing height from Table 4-7 and Figures 4-7 and 4-8, read $\chi u/Q$ from Figures 4-9 through 4-18.

4. Compute the plume rise parameter (K) using the equations in Table 4-3. If both buoyancy and momentum (jet) effects are significant, use the maximum of the two types of plume rise.

5. Using the appropriate maximum emission rate (Q_{max}) and results from preceding steps, compute the maximum contribution from the new source

$$\chi = \left(\frac{\chi u}{Q}\right) \frac{Q_{max}}{u_{crit}} \qquad (4\text{-}18)$$

Short-Term Concentration at Critical Locations With Plume Rise, Stable Conditions

For each stability class estimate the concentration contribution from the new source using the following steps.

1. Determine the concentration versus wind speed relationship by the following substeps for selected wind speeds in the wind speed range associated with critical concentrations.

   (a) Calculate plume rise (ΔH) from the appropriate equation in Table 4-3. Use the maximum of the jet and buoyant plume rises if both are applicable.

   (b) Estimate the height of the plume above the critical location

   $H = h + \Delta H$ (normal, level terrain)

   $H = h + \Delta H + Z_S - Z_R$ (rought terrain, see comments following Equation 4-14)

   (c) For the appropriate travel distance (from Equation 4-13), stability class, mixing layer height (see Table 4-7 and Figures 4-7 and 4-8) and type of terrain (urban or rural), read $\chi u/Q$ from Figures 4-13, 4-14 or 4-18.

(d) Using the appropriate maximum emission rate, (Q_{max}), selected wind speed (u) and $\chi u/Q$ from step 3,

$$\chi = \left(\frac{\chi u}{Q}\right) \frac{Q}{u}$$

(e) Plot the point (χ, u).

2. Selected the maximum concentration from the relationship plotted in step 1.

3. Correct for averaging times other than 1 hour using factors in Table 4-5.

Short-Term Concentration at Critical Locations, Fumigation Conditions

Under certain conditions, emissions from the source will be released into a stable layer (stability class E or F), but part or all of the plume of pollutants being transported downwind will enter an unstable layer which lies over the critical location of interest. This is known as a fumigation situation and may result in abnormally high concentrations at ground level. Three common fumigation situations are the following:

- During the morning hours following sunrise, the base of the temperature inversion which separates the overlying stable air from underlying unstable air is lifted so that it intersects the plume.
- During daytime hours pollutants released in a stable layer over or near a large body of water travel inland and intersect a deep unstable layer.
- During nocturnal hours pollutants released in a stable rural layer intersect the unstable layer overlying an urban area.

After entering the unstable air, concentrations from the fumigated plume tend to approach the limited mixing (trapping) situation associated with Equation 4-11.

The following method may be used to estimate the maximum ground level concentration encountered in a fumigation situation. This occurs just after the plume enters the unstable air.

1. For the stable condition, estimate the plume rise (ΔH) from the equations in Table 4-3. If there is no plume rise, $\Delta H = 0$.

2. For the stable condition and travel distance of interest (Equation 4-13), read σ_y and σ_z values from Figures 4-5 and 4-6.

3. Estimate the height (H) of the plume above the critical location.

   $H = h + \Delta H$ (normal, level terrain)

   $H = h + \Delta H + Z_S - Z_R$ (rough terrain, see comments following equation 4-14)

4. Estimate the concentration contribution from the new source at the point of interest using the lowest wind speed associated with critical conditions, the appropriate maximum emission rate and the results from the preceding steps in the following equation.

$$\chi = \frac{Q_{max}}{\sqrt{2\pi}\, u_{min}\, (\sigma_y + H/8)\, (H + 2\sigma_z)} \qquad (4\text{-}19)$$

CHAPTER 5

BIBLIOGRAPHY OF STATIONARY SOURCE EMISSION INFORMATION

A bibliography of significant documents dealing with emissions, stack characteristics and effectiveness of controls of various types of stationary sources follows.

1. Cuffe, S. T., and R. W. Gerstle, 1967. Emissions from Coal-Fired Power Plants. AP-35. U.S. GPO.

   The Public Health Service and the Bureau of Mines conducted a study of air pollutant emissions from the six main types of coal-burning power plants. The components tested include sulfur oxides, nitrogen oxides, polynuclear hydrocarbons, total gaseous hydrocarbons, solid particulates, formaldehyde, organic acids, arsenic, trace metals, and carbon monoxide. This report relates the effects of variables such as method of operation, type of boiler furnace and auxiliaries, reinjection of fly ash, and type of coal burned to the concentrations of gaseous and particulate pollutants in the products of combustion.

2. Engineering-Sciences, Inc., 1973. Field Surveillance and Enforcement Guide for Primary Metallurgical Industries, EPA-450/3-73-002. US EPA, APTIC, Research Triangle Park, N. C.

   This manual covers a step-wise enforcement procedure intended for use by state and local air pollution control agencies. This manual focuses on the primary metallurgical industry and includes a process description, a discussion of emission sources, typical control devices, stack gas and process monitoring instrumentation, and Inspectors Worksheets for operations in the iron and steel, aluminum, copper, lead, and zinc industries. All major operations in each of those industries were analyzed including an enforcement procedure for the storage and handling of raw materials. Upset conditions and abnormal operating circumstances were examined in relation to their role in air pollution.

   All major pollutants from these five industrial categories were examined. Generally the pollutant of most concern was particulate matter. Sulfur oxides and fluorides are unique to specific metals operations and were discussed accordingly. The manual includes sections on the inspection of pertinent air pollution control devices.

3. Engineering Sciences, Inc., 1971. Exhaust Gases from Combustion and Industrial Sources. APTD-0805. US EPA, APTIC, Research Triangle Park, N. C.

A report is presented of a project which proposed to assemble information on exhaust gas flow rates from selected air pollution sources. The objectives of the project were to determine the extent to which operating variables and process through put rates affect exhaust gas conditions and emission rates, and to recommend exhaust gas conversion factors to be used in the development of implementation plans for air quality control regions. The scope of the project required conversion factors to be developed for 75 major combustion and industrial processes. For each source category, four parameters were evaluated; gas flow rate, gas temperature, gas velocity, and stack height. The source categories are as follows: stationary fuel combusion; refuse incineration; chemical process industry; food and agricultural industry; metallurgical industry; mineral products industry; mineral products; petroleum refinery; pulp and paper industry; and solvent evaporation and gasoline marketing.

4. Hemsath, K. H., and A.C. Thekdi, 1974. "Air Pollution in the Carbon Baking Process," Journal of the Air Pollution Control Association. Vol. 24: 60-63.

Carbon baking process involves evolution of fumes containing hydrocarbons and soot particles which cannot be discharged directly into the atmosphere. An incinerator can be used to clean these fumes. However, length of the baking cycle, nature of the fumes and variations in fume volume and temperature may result in excessive auxiliary fuel usage and inefficient incineration, if the incinerator is not designed properly. This paper describes the application of fundamental knowledge of cerodynamics, reaction kinetics and combustion, together with clear understanding of the process, in design of a highly efficient, fully automated incinerator. The design incorporates a unique but simple control system which results in reduction of auxiliary fuel usage without endangering the safety and efficiency of the incineration process. Operations and economics of the incinerator are described by illustrating a typical baking cycle and comparing actual fuel usage with the thermal ratings of the incinerator. Operating experience from a number of installations in the U.S. and Canada is also noted.

5. Kreichelt, T. E., D. A. Kemnitz, and S. T. Cuffe, 1967. Atmospheric Emissions from the Manufacture of Portland Cement. AP-17. U.S. GPO.

This report summarizes published and unpublished information on actual and potential atmospheric emissions resulting from the manufacture of cement. Raw materials, process equipment, and production

processes are described, as well as the location of plants, and process trends. Emission and related operating data are presented, along with methods normally employed to limit or control emissions from the dry, semi-dry, and wet processes.

6. Lee, W. L., and A. C. Stern, 1973. Stack Height Requirements Implicit in the Federal Standards of Performance for New Stationary Sources," Journal of the Air Pollution Control Association, Vol. 23: 505-513.

The promulgation of Federal standards of performance for certain classes of new stationary sources requires that such sources have minimum stack heights to meet the requirements of national air quality standards. The determination of minimum stack height is complicated by the fact that the performance and air quality standards are stated on different averaging time bases; that the extent of preemption of the assimilative capacity of the air by any individual source will vary among jurisdictions and, in some cases, among different geographic areas of a single jurisdiction; and that some new sources will be designed to emit appreciably less than the performance standard requirement. However, these complications can be resolved and equations and charts prepared from which minimum stack height can be selected.

7. McGowin, C. R., 1973. Stationary Internal Combustion Engines in the United States. EPA-R2-73-210. Shell Development Co., Houston, Texas.

A survey of stationary reciprocating engines in the U.S. was conducted to compile the following information: (1) types and applications of engines, (2) typical pollutant emissions factors for diesel, dual fuel, and natural gas engines, (3) differences between engines that cause emissions to vary, (4) total horsepower and emissions from engines, (5) pollution potential of stationary engines in densely populated regions, and (6) potential emissions control techniques. Where appropriate, gas turbines were included in the survey.

In 1971, an estimated 34.8 million horsepower of reciprocating engines and 35.5 million horsepower of gas turbines were operating in the U.S. The principal functions of engines are oil and gas pipelines (35%), agriculture (22%), and electric power generation (16%). Total NOx emissions from engines are 2.2 million tons annually, of which 42 percent are generated by pipeline engines. Carbon monoxide and hydrocarbon emissions are an order of magnitude lower. Emissions control techniques having potential as short to intermediate term solutions include precombustion chambers for diesel engines and water injection and valve timing modifications for gas and diesel engines. Over the longer term, catalytic reduction of NOx appears to have the greatest potential.

8. Smith, W. S., and C. W. Gruber, 1966. Atmospheric Emissions from Coal Combustion - An Inventory Guide. AP-24, USGPO.

Information concerning atmospheric emissions arising from the combustion of coal was collected from the published literature and other sources. The data were abstracted, assembled, and converted to common units of expression to facilitate comparison and understanding. From these data, emission factors were established that can be applied to coal combustion processes to determine the magnitude of air pollutant emissions. Also discussed are the composition of coal, theory of coal combustion, emission rates, gaps in emission data, and future research needs.

9. Turner, D. B., 1968. "The Diurnal and Day-to-Day Variations of Fuel Usage for Space Heating in St. Louis, Missouri," Atmospheric Environment, Vol. 2: 339-351.

Data on the wintertime emissions of SO_2 from residential and commercial space-heating sources by 2-hour periods were needed for use in a diagnostic dispersion model. Analyses were made of hourly steam-output data from a centralized heating plant and hourly gas-sendout data for December 1964 at St. Louis, Mo., to determine dependence upon temperature and other factors. Methods were then developed to determine the rate of fuel use from residential and commercial space-heating sources for each hour of the day from values for the hourly temperature, the hour of the day, and the day of the week. Relations developed from December 1964 data were tested on data for January and February 1965.

10. National Air Pollution Control Administration, January 1969. Control Techniques for Particulate Air Pollutants. U.S. Dept. of HEW. NAPCA Pub. No. AP-51, USGPO.

Particulate matter in the air originates from both stationary and mobile sources. Although particulate emissions from internal combustion engines are estimated to contribute only 4 percent of the total particulate emissions on a nationwide basis, they do contribute as much as 38 percent in certain urban areas. Industrial sources are the largest single source producing more than 50 percent of the total particulate pollution. Other sources include stationary combustion, construction and demolition, and solid waste disposal. Control techniques are varied and include gas cleaning, source relocation, fuel substitution, process change, good operating practices, source shutdown, and dispersion. Sources vary, but the major methods of control depend on the type and size of particulate emissions. Particles larger than 50 microns may be removed satisfactorily in inertial

and cyclone separators and simple low-energy wet scrubbers. Particles smaller than one micron can be arrested effectively by electrostatic precipitators, high energy scrubbers, and fabric filters. For fuel combustion sources, gas cleaning devices are currently being used with the newer systems controlling both particulate matter and sulfur oxides. For construction and demolition, control can be effected by various means which include loading and venting to air pollution control equipment, wetting down working surfaces with water or oil and using sanitary land fill. Control of local solid waste disposal needs includes sanitary landfill composting, shredding and grinding, and hauling to another locale. Also discussed are emission factors, economic factors, disposal of collected particulate emissions, and current research in control of particulates.

11. National Air Pollution Control Administration, January 1969. Control Techniques for Sulfur Oxide Air Pollutants. U.S. Department of HEW. NAPCA Pub. No. AP-52, USGPO.

The burning of sulfur-bearing fuels produce approximately 75 percent of all sulfur oxides, largely SO_2, emitted into the atmosphere. Of this coal combustion contributes the largest part. These sulfur oxide emissions can be controlled by one or more of the following five major methods. (1) change of fuel or energy source, (2) desulfurize the fuel, (3) increase combustion efficiency, (4) removal of sulfur oxides from flue gas, or (5) dispersion of that gas by tall stacks.

(1) Changing the fuel or energy source can include either switching to a lower sulfur content fuel or switching to a nuclear energy source.
(2) Desulfurizing processes vary with fuels. For coal, cleaning techniques include crushing and flotation. Here sulfur reduction depends on the pyrite content and type of coal. Generally this method produces approximately a 30 percent reduction. For residual oil desulfurizing is accomplished by catalytically treating it with hydrogen. This method reduces the sulfur content by 60 percent.
(3) Increasing combustion efficiency using heat recovery, high pressure combustion, two-step combustion, magnetohydrodynamics, or electrogasdynamics produce varing results.
(4) Cleaning the flue gas can be accomplished by wet or dry limestone-dolomite injection. The former has an 80-90 percent efficiency, and the latter has a 40-60 percent efficiency. Alkalized alumnia sorption may remove 90 percent of the sulfur oxides while the sulfur produced by the regeneration of the metal oxide can partially offset operating costs. Catalytic oxidation recovers and condenses sulfuric acid removing about 90 percent of the sulfur oxides. Caustic scrubbing works, with varying operating efficiencies on small combustion processes.

(5) Dispersion by tall stakes has limited value depending on local conditions and the presence of other sources.

The report contains a discussion of various process sources, dispersion, and evaluation of sulfur oxide emissions.

12. National Air Pollution Control Administration, March 1970. Control Techniques for Carbon Monoxide Emissions from Stationary Sources. U.S. Department of HEW. NAPCA Pub. No. AP-65, USGPO.

Stationary sources contribute 56.2 percent of all man-made CO. This is the sum of: 10.7 percent prescribed agricultural and forest burning, 9.7 percent industrial processes, 7.8 percent solid waste burning, 5.0 percent non-prescribed forest and structural fires, 1.8 percent fuel combustion in a stationary source, and 1.2 percent from coal refuse fires. Alternatives to agricultural and forest burning include utilization, transport and disposal in remote areas, and abandonment or onsite burial. Control of process sources can be effected by using the CO generated as a fuel or burning it as waste but may be prevented by proper design, scheduling, operation, and maintenance. Solid waste disposal could rely on sanitary landfill to replace open-burning or incineration. Prevention is the only available method to reduce CO emissions from non-prescribed forest and structural fires. CO emitted from fuel combustion in a stationary source can be controlled by one or more of the following: properly regulated air supply, long enough residence time, high temperature (up to 2,800°F), good mixing, and elimination of flame contact with cold surfaces. Other methods could include a change of fuel or energy source or switching from small installations to a more efficient central installation. Also included are carbon monoxide emission factors.

13. National Air Pollution Control Administration, March 1970. Control Techniques for Nitrogen Oxides from Stationary Sources. U.S. Department of HEW. NAPCA Pub. No. AP-67, USGPO.

Stationary sources comprise 60 percent of all man-made NOx. This is emitted by various sources of fuel combustion, incineration, other burning, industrial processes, and chemical processes. Of this about 40 percent is attributed to electric generating power plants, using fossel fuels as the source of energy. About 1 percent of the total man-made NOx emitted to the ambient air is formed by chemical sources, mainly related to the manufacture and use of nitric acid. Concentrations from these sources are, however, usually much greater. Commerically demonstrated control techniques for the above vary; for a boiler, a decrease of 30-50 percent NOx can be effected by using a two stage combustion system, 30-60 percent for

using a low excess air in a gas or oil operation, and 30-40 percent when firing is changed from front-wall or opposed to tangential firing. An other means by which the NOx emissions can be decreased, is to change fuel or energy sources. Control techniques with varied commercial success include: (a) the use of electricity to generate heat; (b) relocation to reduce exposure in a densely populated area; (c) catalytic abatement yielding elemental nitrogen, but having short catalyst life and high temperature problems; (d) caustic scrubbing using suspensions of caustic, or calcium hydroxide forming solutions of nitrate and nitrite; (e) incineration using 10 percent more gaseous fuel than required for reaction with oxygen and NOx to produce 75-90 percent reduction in NOx, but because of the fuel rich conditions employed, CO and HC may be present in the exit gas, requiring a second reactor; (f) where strong nitric acid solutions are used urea will inhibit or prevent release of NOx. Speculative control techniques include: (1) lowering boiler peak flame temperature and diluting the combusion by steam and water injection in internal combustion engines, (2) flue-gas recirculation, (3) stack-gas treatments such as those for removal of sulfur oxides from flue-gases, (4) selective catalytic reduction of NOx using ammonia in the presence of oxygen to reduce NOx, (5) absorption on molecular sieves of dry gas low in NOx concentration. Other items covered include nitrogen oxides emission factors and a look at possible new technology in this area.

14. National Air Pollution Control Administration, March 1970. Control Techniques for Hydrocarbon and Organic Solvent Emissions from Stationary Sources. U.S. Department of HEW. NAPCA Pub. No. AP-68, USGPO.

Stationary sources of hydrocarbons and organic solvent emissions account for approximately 50 percent of the organic vapors emitted in the United States. Sources for hydrocarbon emissions include petroleum refining, gasoline distribution and marketing, chemical manufacturing, coal coking, fuel burning, waste disposal, and food processing. Sources of organic solvent emissions include manufacture and application of protective coatings, manufacture of rubber and plastic products, decreasing and cleaning of metal parts, dry cleaning operations, printing, and manufacture of chemicals. Methods used to control these emissions are operational or process changes, substitution of materials, and installation of control equipment. Control techniques include: (1) incineration, (2) adsorption, (3) absorption, and (4) condensation.

(1) Incineration devices are of two types, direct flame and catalytic afterburners.
(2) Adsorption methods collect organic vapors in the capillary surface of the solid adsorbent (usually carbon). After the optimum amount of organic material has been adsorbed the bed is steam stripped to remove the organic material.

(3) Absorption uses a nonvolatile liquid absorbent to absorb the soluble component of a gas phase. Contact between the gas and liquid is provided bubble-plate columns, packed towers, jet scrubbers, spray towers, and venturi scrubbers.

(4) Condenation and collection of organic emissions rely on lowering the temperature of the gaseous stream until the organic material condenses. Condensers are of two types, contact and surface. In contact condensers, the gaseous stream is brought into direct contact with the cooling liquid while in a surface condenser, the vapor and codent are separated by a metal wall. Absorption and condensation cannot achieve high removal efficiencies at low concentrations.

Discussed topics include specific control systems for many industrial process, emission factors, economics and current research.

15. Environmental Protection Agency, February 1973. Control Techniques for Asbestos Air Pollutants. Pub. No. AP-117, USGPO.

Asbestos is the generic name for a group of hydrated mineral silicates that occur naturally in a fibrous form. The technological utility of asbestos derives from its physical strength, resistance to thermal degradation, resistance to chemcial attack, and ability to be subdivided into fine fibers.

The subdivision of asbestos into fine fibers produces particulate matter that is readily dispersed into the atmosphere. Adverse affects of airborne asbestos on human health have been associated primarily with direct and indirect occupational exposures, but a level of asbestos exposure below which there is no detectable risk of adverse health effects to the general population has not yet been identified. Because of the lack of a practical technique of adequate sensitivity for measuring small concentrations of airborne asbestos, neither accurate emission factors nor emission-effect relationships are available.

Engineering appraisals, based on limited data, indicate that the milling and basic processing of asbestos ore (crushing and screening the ore and aspirating the fiber to cyclones for grading) and the manufacture of asbestos-containing friction materials, asbestos-cement products, vinly-asbestos tile, asbestos textiles, and asbestos paper account for over 85 percent of total asbestos emissions. Other sources such as paints, coatings, adhesives, plastics, rubber materials, and molded insulating materials, (2) the use of spray-on asbestos products such as those used for fireproofing or insulating, (3) the demolition of buildings or structures containing asbestos fireproofing or insulating

materials, and (4) the sawing, grinding, or machining of materials that contain asbestos, such as brake linings and molded pipe insulation. In most of the manufacturing operations, the major emissions of asbestos occur when the dry asbestos is being handled, mixed with other dry materials, or dumped into the wet product mix, but the weaving of asbestos fibers into textiles and the machining or sanding of hard asbestos products also produce major emissions.

Emissions are controlled in several ways: (1) by careful handling of dry materials to avoid generating dust, (2) by enclosing dusty operations, (3) by substituting wet processes for dry processes, (4) by wetting dry materials before handling, sawing, or grinding, (5) by cleaning the dust-laden air by drawing it into ducts that lead to filters; and (6) by reducing the amount of asbestos added to products the use of which leads to the generation of emissions. The last technique is particularly applicable to situations where the control of emissions by other methods is very difficult, as with spray application of insulation or demolition of structures. The costs of needed emission control techniques can be estimated from those associated with existing practices.

16. Environmental Protection Agency, February 1973. Control Techniques for Beryllium Air Pollutants. Pub. No. AP-116, USGPO.

Beryllium in almost all forms is known to have adverse effects upon human health. Concentrations as large as 0.01 microgram per cubic meter of air over a 30-day period have been determined to be safe for nonoccupational exposures. Properties of beryllium such as high strength-to-weight ratio, high modulus of elasticity, and low coefficient of thermal expansion make it ideally suited for many aerospace and precision instrument applications. It is also utilized as an alloying constituent in other metals, most extensively with copper, to induce improvements in physical properties. The oxide of beryllium is used as a high-temperature ceramic. Domestically, approximately 300 facilities either extract beryllium or manufacture beryllium-containing products. Beryllium extraction processes generate atmospheric emissions that include beryllium salts, acids, beryllium oxide, and other beryllium compounds in the form of dust, fume, or mist. Facilities engaged in processing beryllium-containing materials into finished products generate a more restricted range of emissions, including beryllium dust from machine shops, beryllium oxide dust from ceramic production, and beryllium-containing dust and fume from beryllium-copper foundry operations.

Beryllium emissions can be controlled by the following classes of gas-cleaning equipment: prefilters, dry mechanical collectors, wet collectors, fabirc filters, and high-efficiency particulate air filters (HEPA filters). The choice of specific control equipment is governed by process variables, effluent properties, and economics. In most cases, emission control costs, including capital investment, operating and maintenance costs, and capital charges, do not exceed 10 to 15 percent of the cost of manufacturing equipment. Beryllium-contaminated waste can be buried at controlled disposal sites unless it presents an explosion hazard. Beryllium propellant and other hazardous beryllium-contaminated wastes can be disposed of by controlled incineration or detonation employing appropriate emission control devices. An appendix to this document presents descriptions of geometrical configurations and performance characteristics of filters and presents examples of specific design parameters and operational features of filters in use in beryllium machine shops and foundries.

17. Environmental Protection Agency, February 1973. Control Techniques for Mercury Emissions from Extraction and Chlor-Alkali Plants. Pub. No. AP-118, USGPO.

The toxicity of mercury, combined with its high volatility, creates a potential health hazard. This publication deals with two sources of mercury emissions, the primary mercury processing industry and the mercury-cell chlor-alkali industry. An effort is made (1) to identify the process steps that may produce atmospheric mercury emissions, (2) to summarize the emission control techniques and low mercury emission processes used or applicable to these industries, and (3) to evaluate these techniques in terms of cost and effectiveness.

The condenser gas stream is the major source of mercury emissions from a primary mercury processing plant. The amount of emissions can be reduced by converting to processes that inherently produce fewer emissions or by treating effluent gases to remove mercury. Process changes that inherently produce fewer emissions include benefication of ore, retort processing, and hydrometallurgical processing. Appropriate control techniques include cooling and mist elimination, wet scrubbing, or adsorption beds.

Major emissions of mercury from a chlor-alkali plant using mercury cells are from the hydrogen gas stream, the end-box ventilation stream, and the cell room ventilation air. The emissions from all sources can be eliminated by converting to the diaphragm-cell process. The cost of converting a 100-ton-per-day plant is estimated to range from $3,700,000 to $8,000,000.

Mercury emissions can also be reduced by the installation of control systems and the use of good housekeeping practices. The hydrogen gas and the end-box ventilation air streams can be treated by cooling and mist elimination, chemical scrubbing, or adsorption beds. No techniques are presently available to treat the cell room ventilation

air; therefore, the control of mercury emissions from this source is dependent on good housekeeping practices.

A control system for a primary mercury facility using cooling (down to 45° to 55°F) and mist elimination would cost between $86,000 and $108,000 depending upon the type of mist elimination device used. The cost of a similar control system for a chlor-alkali plant is estimated at $202,000. Chemical scrubbing, which is too expensive for existing primary mercury facilities, can be applied to the chlor-alkali process at a cost from $160,000 to $350,000 for a 100-ton-of-chlorine-per-day plant.

The cost of a carbon bed adsorption system for a primary mercury facility is estimated at $66,000. The capital investment for an adsorption bed system for a chlor-alkali plant of 100-tons-per-day capacity would range from $279,000 to $349,000.

18. Environmental Protection Agency, March 1973. Guide for Compiling A Comprehensive Emission Inventory (Revised). Pub. No. APTD-1135.

Detailed procedures are given for obtaining and codifying information about air pollutant emissions from stationary and mobile sources. The system has been developed specifically for use by state and local air pollution control agencies. Because of the large amount of information that must be collected, the data must be handled by ADP means.

A uniform coding system for the data is encouraged in order that the information from one region may be compared with that from another. Detailed procedures are given concerning the information to be gathered from each source, the methods to be used to gather the information, the codes to be used to simplify the information on standard coding forms, the geographical and population information needed about the area of interest, the apportionment techniques and emission factors needed, and the methods of displaying the data. The relation of state and local emission inventory systems to the EPA NEDS system is also explained.

19. Environmental Protection Agency, June 1973. Background Information for Proposed New Source Performance Standards: Pub. No. APTD-1352a.

This document provides background information on the derivation of the proposed second group of new source performance standards and their economic impact on the construction and operation of asphalt concrete plants, petroleum refineries, storage vessels, secondary lead smelters and refineries, brass or bronze ingot production plants, iron and steel plants, and sewage treatment plants. Information is also provided on the environmental impact of imposing the standards on new installations.

The standards developed require control at a level typical of well controlled existing plants and attainable with existing technology To determine these levels, extensive on-site investigations were conducted, and design factors, maintenance practices, available test data, and the character of stack emissions were considered. Economic analyses of the effects of the proposed standards indicate that they will not cause undue reductions of profit margins or reductions in growth rates in the affected industries.

20. Environmental Protection Agency, April 1973. Compilation of Air Pollutant Emission Factors (Second Edition). Pub. No. AP-42, USGPO.

Emission data obtained from source tests, material balance studies, engineering estimates, etc., have been compiled for use by individuals and groups responsible for conducting air pollution emission inventories. Emission factors given in this document, the result of the expansion and continuation of earlier work, cover most of the common emission categories: fuel combustion by stationary and mobile sources; combustion of solid wastes; evaporation of fuels, solvents, and other volatile substances; various industrial processes; and miscellaneous sources. When no source-test data are available, these factros can be used to estimate the quantities of primary pollutants (particulates, CO, SO_2, NO_x, and hydrocarbons) being released from a source or source group.

21. Environmental Protection Agency, September 1973. Atmospheric Emissions from the Pulp and Paper Manufacturing Industry. Pub. No. EPA-450/1-73-002.

This report contains information on the nature and quantities of the atmospheric emissions from chemical pulping operations, principally the kraft process. The information was gathered in a cooperative study by the National Council of the Paper Industry for Air and Stream Inprovement, Inc. (NCASI), and the Environmental Protection Agency (EPA). Principal sources of information were a comprehensive questionnaire sent to all the pulp mills, special NCASI studies reported in Technical Bulletins, other literature sources, and a field sampling program conducted by EPA. Control techniques are described and emission ranges reported for each of the operations involved in the chemical pulping processes.

22. Environmental Protection Agency, July 1973. National Emissions Data System Control Device Workbook (NEDS). Pub. No. APTD-1570.

Information is presented on the pollutant control devices and methods most commonly used by the majority of the industries, processes, and facilities grouped under the Source Classification Categories as defined by the National Emissions Data System of the Environmental Protection Agency. Data for each category include the name of the

source classification category; the source classification code; the control equipment identification number; the mean control device efficiency for particulates, sulfur dioxide, nitrogen oxides, carbon monoxide, and hydrocarbons; the range of observed control efficiencies; and the data source from which the information was obtained. These data are intended to be used in the preparation of emission inventories or other similar studies and do not necessarily reflect the extent of pollutant control at any single facility. This workbook supplements information presented in the Guide for Compiling a Comprehensive Emission Inventory (APTD-1135).

23. Slade, D.H., ed. 1968. Meteorology and Atomic Energy 1968. U.S. Atomic Energy Commision. (Available as TID-24190 from NTIS, Springfield, Va.)

This report will serve as a guide to the reader requiring general knowledge of the factors relating the atmosphere and the nuclear industry. It will introduce him to the concepts and terminology of the meteorologist and health physicist. Since it contains equations, graphical aids and an extensive bibliography, the report will serve as a handbook to professional workers in various fields. It contains an outline of subject material which will serve as a text to students which can be used with a variety of other publications in the same and allied fields. The report also serves as a research report containing the results of recent work, the implications of which are not yet fully evaluated. The topics treated include the following:

- Meteorological fundamentals for atmospheric transport and diffusion studies
- Theories of diffusion in the lower layers of the atmosphere
- Diffusion and transport experiments
- The effects of momentum and buoyancy, deposition, precipitation scavenging, and buildings on effluent concentrations
- Meteorological instruments
- Radioactive cloud-dose calculations
- Environmental safety.

The report presents quantitative techniques for treating practical situations along with a broad variety of assumptions engendered by the imperfect knowledge of the atmosphere and the pollutant producing device, rather than hard and fast rules.

24. Turner, D.B., 1970. Workbook of Atmospheric Dispersion Estimates. U.S. Environmental Protection Agency. Office of Air Programs, Pub. No. AP-26, USGPO.

This workbook presents methods of practical application of the binormal continuous plume dispersion model to estimate concentrations of air pollutants. Estimates of dispersion are those of Pasquill as restated by Gifford. Emphasis is on the estimation of concentrations from continuous sources for sampling times of 10 minutes. Some of the topics discussed are determination of effective height of emission, extension of concentration estimates to longer sampling intervals, inversion break-up fumigation concentrations, and concentrations from area, line, and multiple sources. Twenty-six example problems and their solutions are given. Some graphical aids to computation are included.

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